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**PROCEEDINGS OF THE**  
**GODDARD SPACE FLIGHT CENTER WORKSHOP**  
**ON**  
**ROBOTICS FOR COMMERCIAL MICROELECTRONIC**  
**PROCESSES IN SPACE**

**HELD**  
**DECEMBER 2 AND 3, 1987**

**AT**  
**GODDARD SPACE FLIGHT CENTER**  
**GREENBELT, MARYLAND**

{NASA-TM-101233} PROCEEDINGS OF THE GODDARD  
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## 1. BACKGROUND AND INTRODUCTION

The prospect for permanent facilities in space provided by the Space Station Program (SSP) opens up possibilities for working in a new environment so different from the earth. An important aspect of SSP is the early consideration and systematic development of concepts for the commercial utilization of the Space Station and its associated facilities in near-earth orbit. This environment is characterized by its microgravity; high vacuum; solar radiation; relatively clean, non-chemical, nonbiological atmosphere; etc. Considerable thought has been given to this issue, especially in areas related to life sciences and materials research. Another area, in which rapid advances are on-going, and for which the environment of space may hold significant commercial advantages is that of microelectronics.

First considerations of space-based processing of microelectronic elements and components naturally begin with current, familiar, earth-based processes and known microelectronic design concepts. In this regard, potential space application areas include:

1. Advanced materials processing
2. Bulk crystal growth
3. Epitaxial Thin Film growth and related processes

The use of robots and automation systems with special purpose sensors and some degree of intelligence would be essential for space-based commercial operations in any of these areas. These same operations are currently being automated on Earth. Reasons for highly or fully automated operations in space are dominated by the extreme high cost of man-hours in the space environment.

On the other hand, it is reasonable to expect that the environment of space itself will eventually lead to entirely new concepts for microelectronic devices as well as for associated production processes.

In either case, space-based robots, sensors and process specific systems would be essential for practical and cost effective commercial space operations. While some thought has been given to potentially useful space-based microelectronic processes, little attention has yet been given to the establishment of requirements for robots to support and/or carry out these processes.

The following types of questions are of central importance in regard to robotics for commercial microelectronic processes in space:

1. What potential advantages support the commercial use of space for production processes for microelectronic materials, elements, components and assemblies?
2. Which of these processes require robotic assistance and what are the associated requirements for the robot, sensors, etc? What are the technical drivers?
3. How might microelectronic concepts and processes be modified to realize the maximum advantage of the space environment to produce better systems?
4. What further robot system requirements would be added by advanced microelectronic concepts and processes?
5. What are the robot requirements for terrestrial and/or space-based R&D in support of commercial microelectric processes space.
6. What technology gaps or state-of-the-art short falls currently exist in regard to the above robotic issues?
7. What technology development costs and schedules can be expected?

These and other related questions motivated the Office of Space Commercialization at the Goodard Space Flight Center (Code 700.6) to conduct this the first workshop in "Robotics for Commercial Microelectronic Processes in Space," on December 2 and 3, 1987. The workshop, intentionally kept small, was attended by the twenty-five persons listed in Appendix A, representing the full range of relevant interests and technologies. The following sections of this report contain descriptions of the workshop organization and procedures, and of the resulting findings, conclusions and recommendations.

## 2. PURPOSE AND OBJECTIVES

The purpose of the workshop was to study potential applications of robots for cost effective commercial microelectronic processes in space and to define the associated robotic requirements. Ideally, the results of the workshop will ultimately be organized into a NASA technology development plan and demonstration program to enhance NASA's impact on the commercialization of space.

The objectives of the workshop in support of its purpose include:

- o To assemble and support discussions between recognized experts in technical areas related to commercial microelectronics and robotics.
- o To identify the critical issues related to commercial microelectronics in space, present and future, using robots.
- o To identify a priority listing of potential robot applications including:
  - Detailed advantages and disadvantages of the space environment for commercial and/or R&D microelectronic processes.

- The need for robots for space-based R&D leading to potential commercial processes.
  - The need for robots for space-based commercial microelectric processes.
  - Requirements for robotic activities, sensors, system intelligence, etc.
  - Current technology deficiencies.
- o To identify robotic applications development elements not covered by other NASA development programs.

### 3. ORGANIZATION OF WORKSHOP

#### 3.1 The Program

A program was designed to support the successful achievement of the above workshop objectives. Details of this program presented in Figure 1, show that it consisted of five separate sessions over the two-day workshop period - including a GSFC facilities tour. The first, second and final sessions were plenary sessions. The fourth session entailed smaller workshop panel meetings to simplify the task of getting down to details on the issues raised during the plenary discussions. The final session was dedicated to presentations of panel results to the entire group, to open discussions and, finally, to a wrap-up of findings, conclusions and recommendations.

#### 3.2 The Process

The process or flow of the workshop inherent in the program of Figure 1 is diagrammed in Figure 2. Figure 2 shows the workshop activities and planned outputs at each stage of the process.

FIGURE 1. WORKSHOP PROGRAM DETAILS FOR 2 DECEMBER 1987

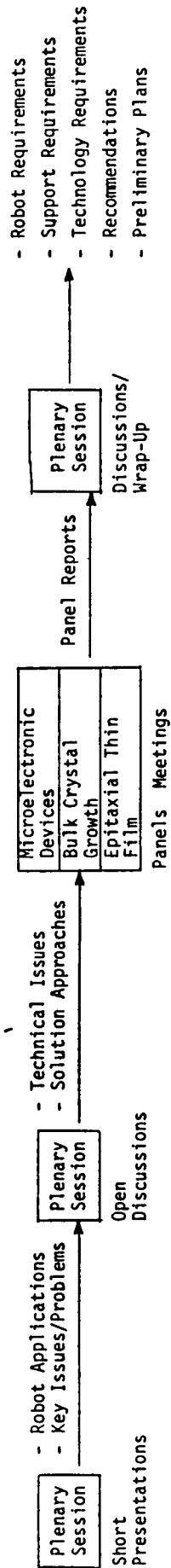
Session	Activity	Purpose	Desired Output
I. 9:00 am - 12:30 pm	Short presentations by selected participants	Descriptions of <ul style="list-style-type: none"> <li>- SOA</li> <li>- Future directions</li> <li>- Perceived difficulties</li> </ul>	List of Probable <ul style="list-style-type: none"> <li>- Robotic applications</li> <li>- Key issues &amp; problems</li> </ul>
II. 1:30 pm - 4:00 pm	Open discussions, all participants	Group focus on <ul style="list-style-type: none"> <li>- Perceived problems</li> <li>- Potential solutions</li> </ul>	List of <ul style="list-style-type: none"> <li>- Technical issues</li> <li>- Solution approaches</li> </ul>
III. 4:00 pm - 5:15 pm	Tour of GSFC Robotics Laboratory & Hitch Hiker Project		
IV. 8:30 am - 12:00 pm	Panel workshop meetings	Address issues <ul style="list-style-type: none"> <li>- Identify tech gaps</li> <li>- Recommended approaches</li> </ul>	Panel Reports: <ul style="list-style-type: none"> <li>- Specific robotic requirements</li> <li>- Development requirements</li> <li>- ROM costs</li> </ul>



FIGURE 1. WORKSHOP PROGRAM DETAILS FOR 3 DECEMBER 1987 (Cont'd.)

Session	Activity	Purpose	Desired Output
V. 1:00 pm - 2:30 pm	Plenary discussions around panel reports	Wrap-up findings	<ul style="list-style-type: none"> <li>- Robotic requirement</li> <li>- Support requirements</li> <li>- Technology develop- ments</li> <li>- Recommendations</li> <li>- Preliminary plans</li> </ul>

FIGURE 2. WORKSHOP FLOWCHART



The workshop began with the following short invited presentations by attendees representing the different aspects of robotic applications for commercial microelectronic processes in space:

1. Modular, Kinematically-Redundant Manipulators -  
Jack Thompson, RRC
2. Automation in Crystal Growth - Robert Mazelsky,  
Westinghouse R&D
3. Chemical Vapor Transport Experiment - Dave Yoel, BCSDC
4. Robotics and Materials Processing in Space - Lisa McCauley,  
Battelle
5. Robotics Requirements for Epitaxial Thin Film Growth for  
Microelectronics in Space - A. Ignatiev, University of  
Houston
6. IC Manufacture in Vacuum - Tom Seidel, UCSB
7. Robotics for Commercial Microelectronic Processes in Space -  
Neville Marzwell, JPL
8. Microgravity Robotics - Douglas Rohn, NASA/LeRC
9. Industrial Space Facility - Olav Smitstad, ISF
10. Concept Development Ideas - Tom Taylor, SPACEHAB

Presentation materials for these ten (10) papers presented in Session I are included in Appendix C.

The presentations were logically grouped before the workshop into the following three categories:

- (1) Microelectronic Processes
- (2) Robot Capabilities
- (3) Support Elements

Figure 3 shows preliminary lists of issues which were also developed before the workshop for each of these categories. The purpose of the presentations and the information in Figure 3 was to provide some common starting point for and to stimulate the open discussions in Section II.

Potential robotic applications introduced by the presenters or resulting from discussions during Session I were further discussed in Session II. Session II was basically a "brainstorming" session, organized to promote the free flow of ideas and constructive exchanges among all of the participants. The purpose of Session II was to narrow down the list of robotic applications to provide a near-term practical focus. Furthermore, discussions were centered on the need to identify technical issues, problems and solution approaches for each application.

Among the many useful results of Session II, the following three robotic application areas were selected from all those discussed as having the greatest immediate importance:

1. Microelectronic devices
2. Bulk crystal growth
3. Epitaxial thin film growth

These were adopted as the focus topics for the workshop panels in the following sessions. Those who were able to attend both days of the workshop were organized into three panels to cover the above three robotic application areas. Panel members were selected to give each panel a cross disciplinary character. Each panel was made up of at least one specialist from the area of the panel's focus topic as well as representatives from

FIGURE 3. PRELIMINARY ISSUES LISTS

<u>Microelectronic Processes</u>	<u>Robot Capabilities</u>	<u>Support Elements</u>
Process Description	Type of Device/System	Facilities
Process Requirements	Design Functions	- Flight
Energy Requirements	Kinematic Specifications	- Ground
Environmental Requirements	Dynamic Specifications	Logistics
	Accuracy/Repeatability	Ground Support/Operations
	Structure	Launch and Recovery
	Command Modes	- Robot
	Sensors	- Process Materials
	Control Parameters	Management
	Special Features	- Systems
	Operational Flexibility	- Interfaces
	Maintainability	- Pricing

the robotics and the space environment/facilities communities. The three panels and their respective members are listed in Figure 4.

A generic robotic functions list (see Figure 5) was also developed in Session II to include all functions related to microelectronic processes with potential applicability to commercial operations in space.

The purpose, then, of the workshop panels was to specialize the robotic functions from Figure 5 to the specific focus topic taken up by each panel. This was achieved in Sessions IV by each of the three panels by means of the following process:

1. Identify (from Figure 5) appropriate relevant robotic functions
2. Consider robotic requirements for each function
3. Determine technical needs/difficulties or technical problem areas
4. Develop possible solution approaches
5. Define technical development requirements
6. Draw conclusions
7. Develop recommendations

The results from each of the panels were presented to the entire workshop body in Session V for further open discussions before final wrap-up.

**FIGURE 5. POTENTIAL ROBOTIC-BASED FUNCTIONS FOR COMMERCIAL MICROELECTRONIC PROCESSES IN SPACE**

1. Material supply
2. Materials cleaning/preparation
3. Sample or work piece installation and removal
4. Interprocess transportation
5. Material slicing/cutting/etc.
6. Process monitoring
7. Materials characterization
8. Process control
9. Maintenance/repair
10. Configuration/reconfiguration
11. Fault detection/analysis/planning
12. Fault recovery
13. Expert Systems (Robot based)
  - o planning
    - multiple project
    - single project
  - o queuing
  - o pattern recognition
    - scene analysis
    - sample analysis
14. Calibration
15. Environmental control
16. Hazard control
17. Operator interface
18. Product completion and packaging
19. Waste management

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#### 4. FINDINGS

An enormous amount of information was brought forward during the present workshop - by the presenters in Session 1 and also as a result of open discussions among workshop participants during subsequent sessions. Highlights of relevant workshop information are listed below under the general headings

(1) Microelectronic Processes

(2) Robot Capabilities

(3) Support Elements

In most cases more detailed information on each topic can be found in the presentation materials contained in Appendix C.

##### 4.1 Microelectronic Processes

##### 4.1.1 Terrestrial Operations

- o Evolution towards "hands-off", fully automated operations
  - Furnace operations/controls
  - Handling of in-process wafers
  - Device assembly
  - Inspection and test
- o Advanced manufacturing processes and facilities are under development



#### 4.1.2 The Space Environment

- o Significant (unique) advantages exist
- o Very quiet, very clean environments are possible/necessary
- o New materials, products and process capabilities are predicted

#### 4.1.3 Space Operations

- o Complete automatic IC and device production in space is the dream
- o Man is the most expensive commodity in space
- o Experiments and R&D demonstrations (microelectronic processes are planned for future shuttle flights and for the space station.
- o "Man-in-the-loop" operations will be necessary for early operations - either directly or telerobotically.
- o Process concepts for operations in space are under study
  - Bulk crystal growth
  - Material transport systems
  - Epitaxial thin film growth
  - Advanced sensors and control schemes
- o The best process designs are based on the use of simple robotic concepts and mechanisms

- o There is strong (and alarming) international competition for the use of space for microelectronics and materials processing

- Japan
- Russia
- Germany
- Canada

## 4.2 Robot Capabilities

### 4.2.1 Terrestrial Applications

- o Highly productive and reliable robotic solutions for preprogrammed, repetitive operations
- o Broad variety of configurations, multiple DOE systems available
- o Real-time sensory controls and simple machine intelligence are under development/test

### 4.2.2 Special Requirements for Space

- o Ultra cleanliness
- o Advanced manipulation capability
  - Dexterity
  - Work envelope volume and access
  - Acceleration/speed
  - Positioning precision

- o Smooth motion (micro-G)
- o Active damping
- o Force control/limitation
- o Safe operations
- o Design simplicity and reliability
- o Low mass
- o Engineered for space operations (micro-G, vacuum, thermal management, etc.)
- o Upgradeable/expandable, designed for growth

#### 4.2.3 Space Applications (Typical)

- o Cleaning and maintenance of process equipment
- o Transport of samples within processing stations
- o Sample transport between processing stations
- o Handling and operations with toxic process materials
- o Replacement of "dirty" humans

#### 4.2.4 Generic Advanced Technology Needs (For Space)

- o Integrated sensing capabilities:
  - Vision, force and tactile sensing

- Completely automated scene analysis capabilities
- Visual sensing - based controls
- o Control strategies and software systems for force-guided control of robots moving in contact with other bodies
- o Efficient motion and task planning algorithms
- o Geometric algorithms and analysis techniques for mechanization planning

#### 4.3 Support Facilities

##### 4.3.1 Existing and/or Near-Term Space Facilities

- o National Space Transportation System
- o SPACEHAB
  - NSS middeck modules
  - Man-tended capabilities
  - Pressurized shirt sleeve environment
  - Robotic/automation support built-in
  - NSS berthing or space station attachment
  - Utilities provided (by NSS or SS)
- o Industrial space facility
  - Launched/served by NSTS

- Man-tended capabilities
- Pressurized/shirt sleeve environment
- Robotic/automation support built-in
- Built-in power source/resource management systems
- On orbit mission extension/expansion
- Meteoroid/radiation shell protection

o U.S. space station

## 5. CONCLUSIONS/RECOMMENDATIONS

The general conclusion of the workshop is that the environment of space provides a number of potentially very significant advantages in regard to commercial microelectronic processes. These advantages are principally associated with the microgravity, cleanliness, quietness, high vacuum and thermal characteristics of space. There are a corresponding number of technical challenges in regard to testing and, ultimately, realizing these advantages. However, the necessary test and development effort appears to be justifiable in terms of the anticipated benefits of; (1) increased understanding of associated physical phenomena - both in space and on earth, (2) improved microelectronic process - in space and, possibly, also on earth, and (3) new microelectronic device/ component design concepts made possible by (1) and/or (2).

Robots will be essential for microelectronic processing in space during the initial concept testing, R&D and ultimate production phases. The trend for microelectronics on earth is towards more automation within and among all production processes. Some aspects or activities associated with the above phases of microelectronic processes in space could be handled by technical personnel. However, because of the extreme high cost

of man in space, man's role in this, as well as most other programmable space-based process/activity is more practicably that of a manager rather than a doer. Furthermore, there are perhaps microelectronic processes which could be carried out in space only by robots and not by man. Cleanliness, quietness, accuracy/timing, and reliability during repetitive, monotonous tasks are among the desirable characteristics that are easier to build into robots than into technicians.

Some real progress was made during the workshop towards the development of the requirements for robots for space-based microelectronic processes. These some requirements probably apply for the broader more general area of robot-supported material processing in space. Specific requirements and detailed specifications are dependent on application. The important design issue of whether to develop and use single, more flexible, general purpose robots or multiple, simpler, special purpose robots is also dependent on application.

The robot requirements identified during the workshop, in general, are those which relate to extending human capabilities in the space environment and to supporting the specific microelectronic processes discussed during the workshop. These requirements include long reach and large operating volume, micro precision accuracy for pick and place operations, cleanliness, ultra high reliability, integrated-sensory-coupled controls, etc. The technology developments associated with each of these requirements were also identified during the workshop. Both robotic requirements and necessary technology developments are summarized in the workshop panel reports in Appendix B.

The general recommendation of the workshop is to study the microelectronic processes discussed in the workshop in greater depth to establish a more detailed understanding of the requirements and advantages for space operations. On going and planned NASA robot developments programs are for the most part driven by EVA requirements. A specific recommendation of this workshop is to apply an appropriate effort towards identifying and meeting the requirements for IVA robots.

The following list of activities represents the recommended follow-on from the workshop beyond the selection of the most promising microelectronic processes mentioned above:

1. Identify a priority list of materials, processes, and robotic technologies to be investigated for near term use in space. Perform a cost benefit trade-off study to provide practical guidance on the use of man versus robots in space-based developmental and commercial microelectronic processes. This cost/benefit study should necessarily be focused on specific microelectronic processes in order to provide the most detailed and meaningful results.
2. Develop a conceptual design for a robotic space facility for applied R&D in microelectronics.
3. Develop a conceptual design for a ground test version of a microelectronic facility which demonstrates the key features.
4. Identify what interim flight experiments could be developed, such as, small attached payloads, which would test key robotic functions at reasonable cost in the near future.
5. Layout a program plan which encompasses the programmatic to accomplish the above elements.

APPENDIX A  
Robotics for Commercial  
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December 2 - 3, 1987  
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## **APPENDIX B - WORKSHOP PANEL REPORTS**

- Microelectronic Devices
- Bulk Crystal Growth
- Epitaxial Thin Film Growth

## Microelectronic Devices Panel Report

### 1. Approach

(1) Considered two earth-type processes carried out in space

- o Fabrication of Large Photovoltaic Arrays
- o Crystal Substrate Production

(2) Subjected these to "Workshop Process"

- o Which functions (from Figure 5) have potential robotic solutions?
- o What are solution possibilities?
- o Technical developments:
  - what difficulties
  - what development requirements

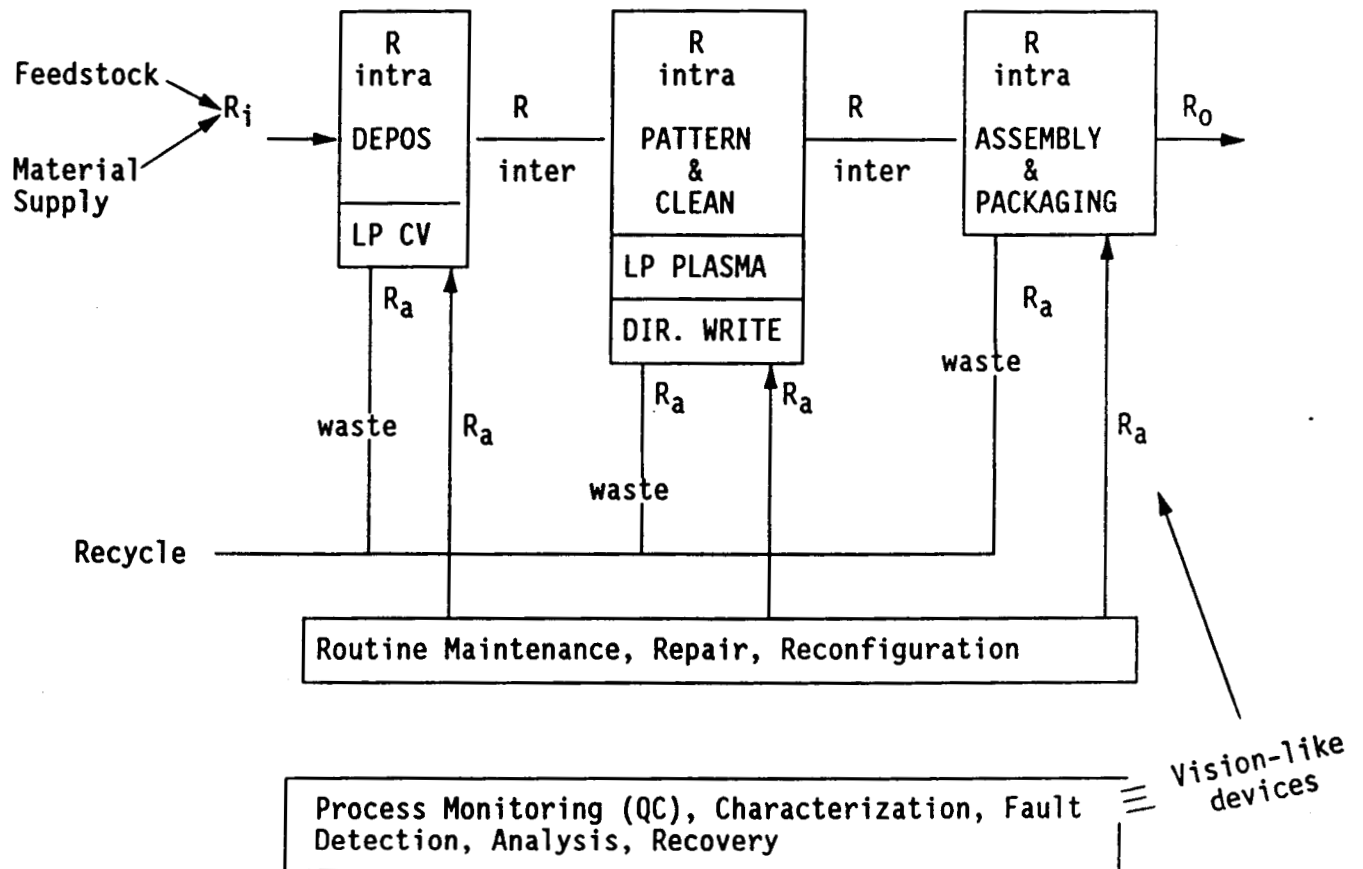
(3) Analyzed findings and drew conclusions/recommendations

### 2. Process Description

(1) Fabrication of large area solar cell arrays to provide power for space colonies

- o Figure B-1 shows general configuration and process flow.
- o Assume that feedstock is substrates with layers intact.

FIGURE B-1. SOLAR ARRAY FABRICATION PROCESS.



- o "R's" on flow diagram signify robotic installations (or opportunities).

- $R_a$  = general purpose robot
- $R_i$ ,  $R_a$ ,  $R_{intra}$ ,  $R_{inter}$  are dedicated, specialized robots.

## (2) Production of crystal substrates

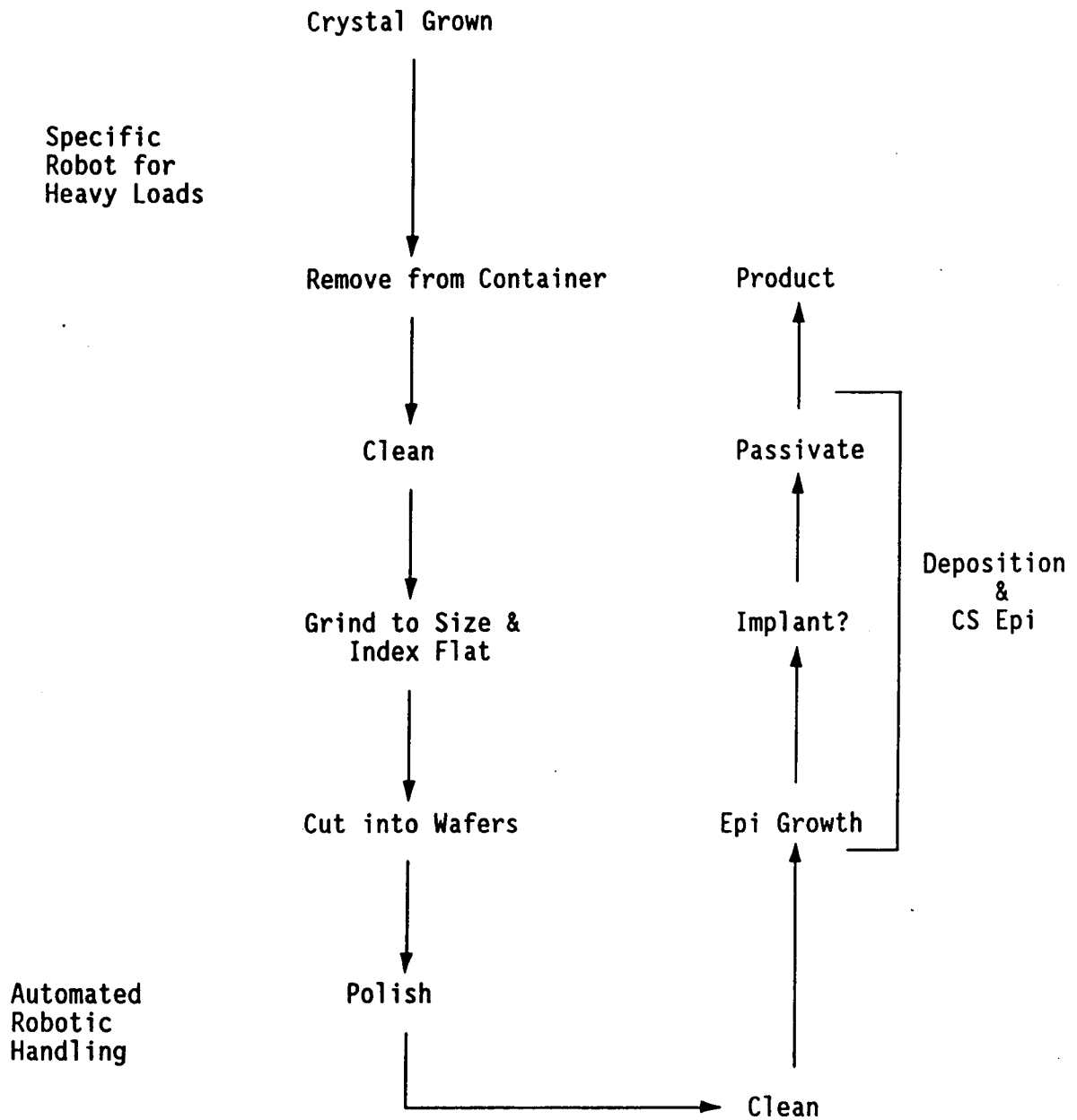
- o Figure B-2 shows general process flow
- o Feedstock is bulk crystal material
- o Potential robot units are indicated on Figure C-2
- o Intra and inter process robots may also be necessary - similar to solar array fabrication process

## 3. Identified Technical Needs Difficulties

### (1) Photovaltaic arrays

- o The accurate, real time determination of a robots location within the fabrication facility and relative to the work piece.
- o The accurate, real-time positioning and indexing of wafers within the work piece/array assembly.
- o Robot cleanliness

FIGURE B-2. CRYSTAL SUBSTRATE PRODUCTION (e.g.,  $G_a A_s$ )





(2) Crystal substrates

- o Interfacing between process stages.
- o Highly accurate registration/indexing of work pieces at each process stage.

4. Development Requirements

(1) Appropriately designed manipulators

- o SOA position accuracies for well designed units are just about adequate.
- o End-point controls (using lasers) would provide a fully adequate solution for future systems.

(2) Micro grippers and associated tooling

- o Really, a set of robotic tweezers.

(3) Specially designed interface schemes and equipment for linking stages of automatic processes

(4) Sensors to detect tool/part orientations, for process quality and completion monitoring, and for final inspection.

(5) Locomotion schemes/systems for robots within space fabrication work space or fixed facility.

(6) Software systems for controls, sensor integration and some intelligence in automatic process execution.

5. Results/Conclusions

- (1) Most of these (above) development requirements are being carried out within NASA A&R Programs at NASA centers and at university and commercial laboratories, especially in regard to external vehicular activity, EVA, robotics.

6. Recommendations

- (1) Need process - specific requirements and design studies for robotic activities.
- (2) Need a specific system/demonstration program for an IVA robot
  - o Systematic terrestrial demo program.
  - o Ultimately, need a space-based demonstration.
  - o Highly probable that a free flying capability will be essential and cost effective.

## Bulk Crystal Growth Panel Report

### 1. Approach

- (1) Define bulk crystal growth process: growth of a crystal by any process including chemical, physical, liquid, etc. ????
- (2) Define panel objective: identify potential roles of robotics (both teleoperated and autonomous) for bulk growth processes in space.
- (3) Define robot: a multipurpose manipulator with sensing and "smart" processing capabilities, capable of being programmed by a person.
- (4) Apply the "workshop process" to space-based bulk crystal growth.

### 2. Process Description

The bulk crystal growth process was characterized by the following three phases of activity:

- (1) Preprocessing - including such things as material transport, sample storage, inspection, equipment/material installation, equipment servicing, and process planning.
- (2) Processing - including such things as sensing, data analysis, actuation, warm-up, growth, and cool-down phases.
- (3) Postprocessing - including such things as sample removal, transport, storage and inspection, and clean up.

3. Position of the Panel

- (1) Robots are relatively more useful (as compared to "hard" automation) in a variable and often unpredictable environment such a crystal growth, involving equipment sharing among different process phases.
- (2) Robot performance requirements are driven by the processing phase activities.
- (3) Pre and post processing phase activities require less accuracy but probably more robot flexibility.
- (4) Robots are, therefore, probably easier to apply in the pre and post processing phases of the bulk crystal growth process.

4. Identified Technical Needs/Difficulties

- (1) SOA generic robot specifications include:
  - Transport objects with a mass of 1-50 kg and size of 1 mm to meter cubed
  - End point accuracy Of 0.1 mm to 1 mm
  - Path following accuracy of 5-10 mm
  - Reach of 0.5-2 meter
  - Mobility of 5-20 meter (facility dependant)
- (2) The ability to identify cracks - this seems to require the spectral and resolution characteristics of the human eye.

- (3) The need for robots with a wide range of process sensing and position accuracy capabilities.

5. Development Requirements

- (1) The following represent specific robot capabilities, not presently existing, appear to be necessary to support robot-based bulk crystal growth in space:

- Micro/macro motion control (1 micron to 1 meter) in a single manipulator
- Accuracy of 0.1mm over 1 meter travel
- Detect 1 gram contact force
- Ability to control tip motion of a 1 meter long tool with 0.1 mm accuracy
- Entire manipulator to fit and work within 12" x 12" x 6" space
- Sense accelerations of 10 to the -6 G between 0.001 and 100 Hz
- Sense forces of 1 gram to 10 lb
- Sense temperatures of 0-500 deg centigrade with 1 deg accuracy
- Sense pressure 10 to the -7 torr to 10 atm
- Multi-spectrum vision (UV to IR) 2D/3D, 1000x 1000 pixel

- (2) The major technical trade-off is between developing robots with a wide range of sensing and position capabilities vs using a combination of a more simple robots and special purpose tools.

## 6. Results/Conclusions

- (1) It appears that robots could/should be usefully applied to the crystal bulk growth process.
- (2) No known show-stoppers were identified and robotic applications seem entirely feasible.
- (3) Further, in-depth studies are, however, necessary for more specific details.
- (4) An unresolved issue is whether to go the route of sophisticated, highly flexible, general purpose robots or combinations of simpler, special purpose robots combined with special purpose tools and "hard" automation.
- (5) At any rate, design studies of specific bulk processing facilities are needed to determine the mix of flexible robots, telerobotics and hard automation for efficient, cost effective operations in space.

## 7. Recommendations

- (1) Perform design studies of specific space-based bulk crystal processing facilities to address the above questions, concerns and open issues in regard to potential commercial operations.
- (2) Carry out a study for a terrestrial/space robotics demonstration plan to support commercial microelectronic processes (including bulk crystal growth) in space.

## Epitaxial Thin Film Growth Panel Report

### 1. Approach

- (1) Considered highly automated epitaxial thin film growth processing facility of the type presently under study at the NASA CCDS at the University of Houston.
- (2) Reviewed this facility in the context of the purposes of the present workshop.
- (3) Analyzed findings and drew conclusions/recommendations

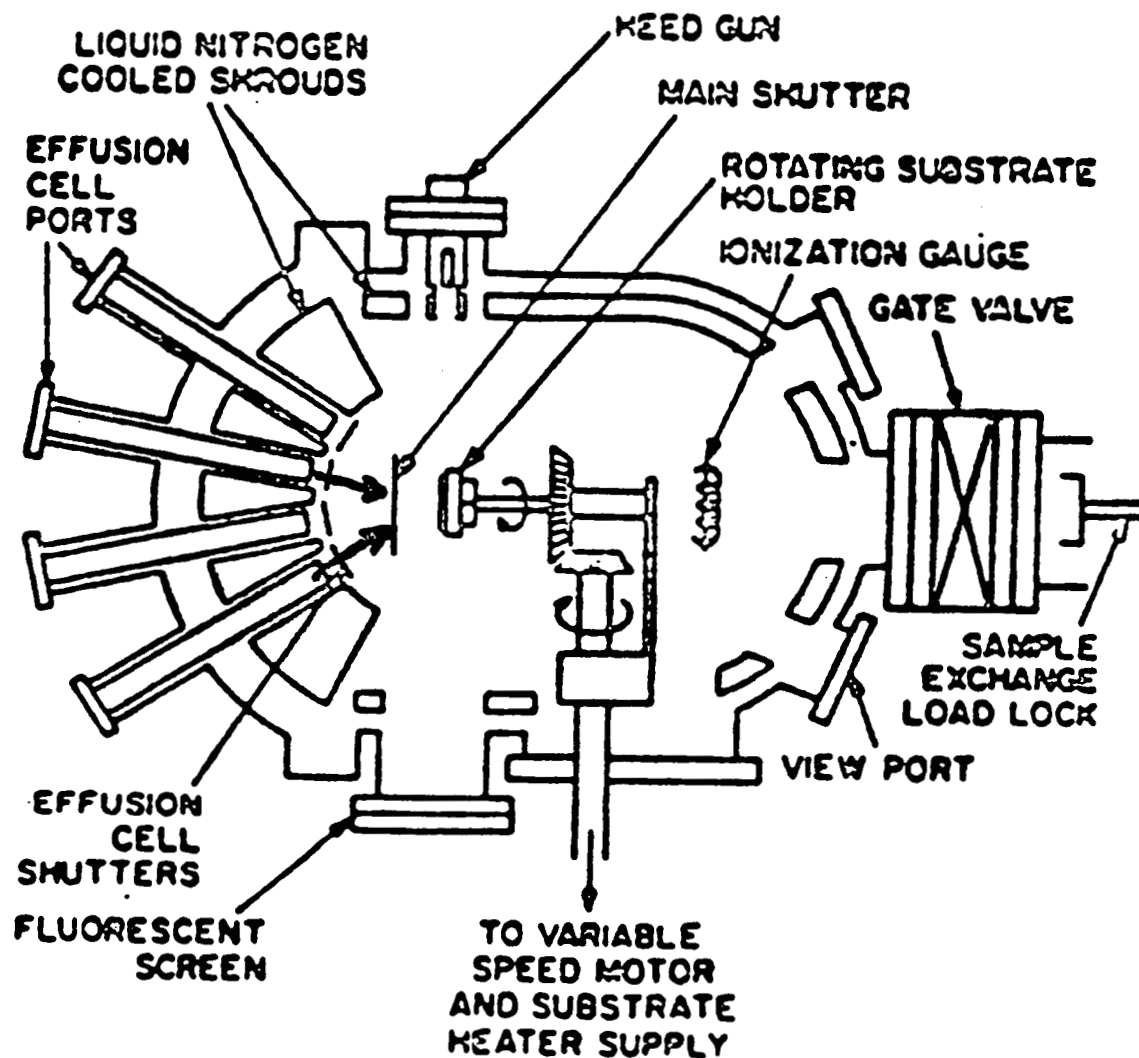
### 2. Process Description

- (1) See Figure B-3 for sample process and configuration.

### 3. Identified Technical Needs/Difficulties

- (1) The supply and resupply of raw materials to the epitaxial growth process in the required ultra high vacuum environment.
- (2) Configuration/reconfiguration or the process of setting up for specific materials/films/designs prior to the epitaxial growth process.
- (3) Robot mobility within the epitaxial growth facility.
- (4) Low out-gassing and particulate counts are essential to the epitaxial growth process; i.e., an ultra clean environment.
- (5) The necessarily accurate movement, transport and positioning of materials and work pieces with the epitaxial growth facility requires:

FIGURE B-3. SPACE-BASE EPITAXIAL THIN FILM GROWTH FACILITY





- Multiple degree of freedom (DOF) (6 or more) manipulators
- With sufficient reach range and position accuracy
- With vision system information and/or real time feedback.

#### 4. Development Requirements

##### (1) Very clean, low maintenance robots

- Lubrication and sealing suitable to pressures of  $10^{-14}$  torr
- Material properties appropriate for  $10^{-14}$  torr
- High reliability, long life (>5 years)

##### (2) Flexibility of manipulation

- 6 or more DOF
- Access to large volume ( $100 \text{ m}^3$ )
- 5 m reach range
- 0.1 mm tool/tip position accuracy
- Payload mass up to 20 Kg

##### (3) Special purpose tools or end effectors

- Precision micro tweezers

- Built in tactile sensing and controls to avoid sample damage

5. Results/Conclusions

- (1) Many of these (above) development requirements are already being approached by on-going technology development programs but not for the mobile, long reach system envisioned for the epitaxial growth facility.
- (2) Of particular importance, besides robot arm reach, are the micro tweezers with tactile sensing.
- (3) The combined speed, accuracy, reach, and mass operational envelop is also of special importance.
- (4) Process material and robot manipulator out-gassing and particulate (cleanliness) requirements need to be handled in design. Not presently being addressed. Requirements are about 6 orders of magnitude beyond the SOA. Need a robot that cleans itself.
- (5) Non robotic, automated control of valves and other hardware should be designed into hazard control systems/strategies. But robot should have a designed secondary role in hazard recovery.
- (6) Fault analysis is feasible using state-of-the-art vision and scene analysis systems.
- (7) The above maintenance (especially cleanliness) and repair (reliability) requirements for an EVA robot are not presently being addressed by the GSFC Flight Telerobotic Servicer (FTS) project.

6. Recommendations

- (1) The above critical issues should be approached by a careful detailed design.
- (2) Phased development and demonstration programs should be initiated, especially for cleanliness, and manipulation and mobility issues. These, of course, would be tied into the development of the epitaxial growth facility.

**APPENDIX C**  
**WORKSHOP PRESENTATIONS**

SESSION 1 - 9:00 am - 12:30 pm

1. Modular, Kinematically-Redundant Manipulators - Jack Thompson, RRC
2. Automation In Crystal Growth - Robert Mazelsky, Westinghouse R&D
3. Chemical Vapor Transport Experiment - Dave Yoel, BCSDC
4. Robotics and Materials Processing in Space - Lisa McCauley, Battelle
5. Robotics Requirements for Epitaxial Thin Film Growth for Microelectronics in Space - A. Ignatiav, University of Houston
6. IC Manufacture in Vacuum - Tom Seidel, UCSB
7. Robotics for Commercial Microelectronic Processes in Space - Neville Marzwell, JPL
8. Microgravity Robotics - Douglas Rohn, NASA/LeRC
9. Industrial Space Facility - Olav Smitstad, ISF
10. Concept Development Ideas - Tom Taylor, SpaceLab

ROBOTICS RESEARCH CORPORATION

# ROBOTICS RESEARCH CORPORATION

## MODULAR, KINEMATICALLY- REDUNDANT MANIPULATORS

- PRODUCTS AVAILABLE TODAY
- POTENTIAL FOR IVA SPACE  
MICROELECTRONIC  
MANUFACTURING

Jack M. Thompson Jr.

Manager,  
Servomechanism  
Engineering

ROBOTICS RESEARCH CORPORATION

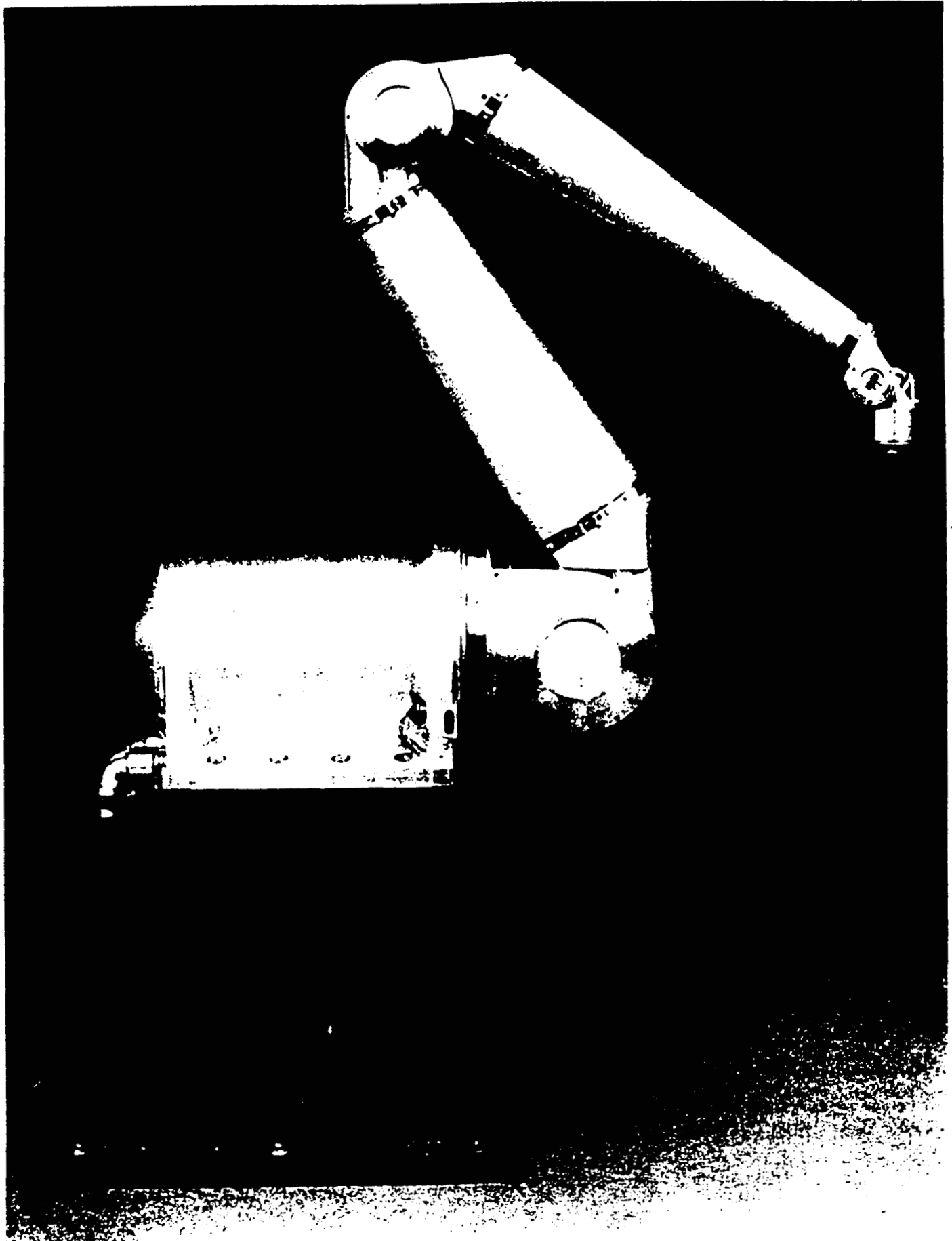
ROBOTICS RESEARCH

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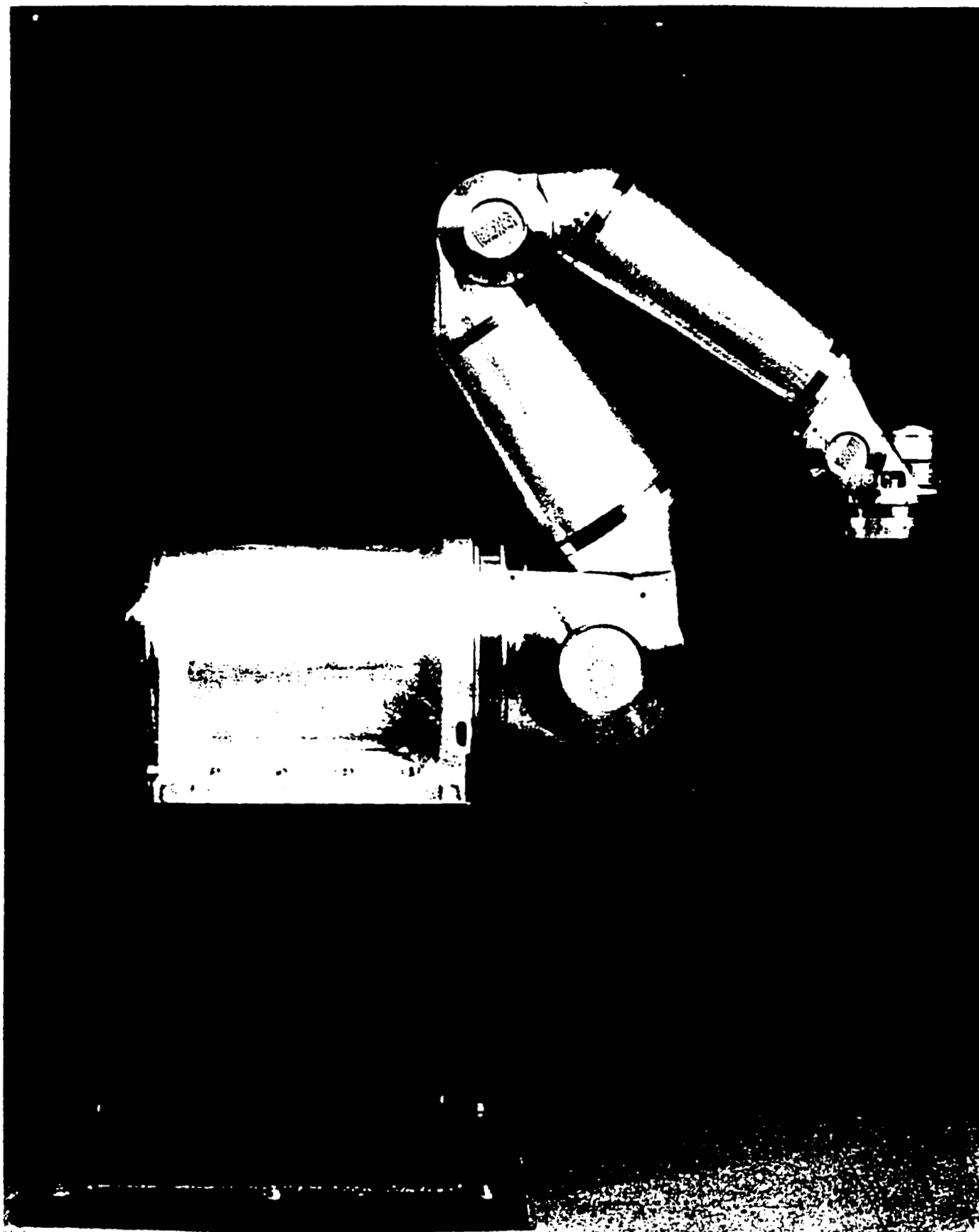
## CURRENT TECHNOLOGY

K-SERIES DEXTEROUS  
MANIPULATORS

***A FAMILY OF  
HIGH PERFORMANCE  
MODULAR ROBOT ARMS  
FOR  
FACTORY AUTOMATION***



K-2107HR DEXTEROUS MANIPULATOR

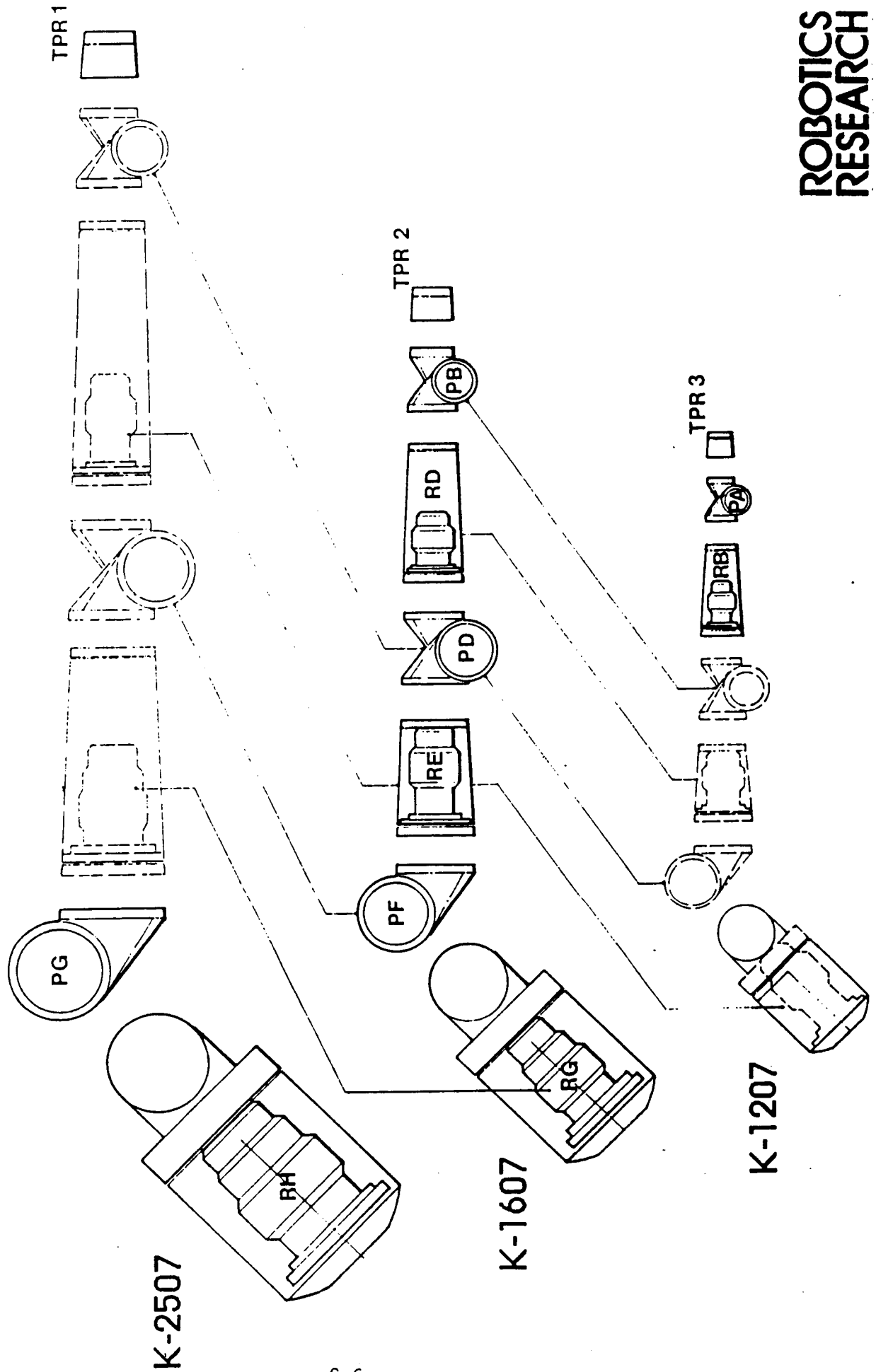


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K-1607 DEXTEROUS MANIPULATOR



# ROBOTICS RESEARCH MODULE FAMILY



## K-SERIES DEXTEROUS MANIPULATORS

---

### HUMAN-ARM-LIKE DEXTERITY

- OFF-SET PITCH JOINTS
- FOLD UP / REACH
- KINEMATIC REDUNDANCY (7+ D. O. F.)
- SPEED / ACCELERATION / PAYLOAD

## K-SERIES DEXTEROUS MANIPULATORS

---

### **"EXOSKELETON" STRUCTURAL PACKAGE**

- LOW MASS / HIGH STIFFNESS
- TORQUE LIMITING CLUTCHES
- STRUCTURE ENCLOSES MECHANISM
- INTERNAL WIRING HARNESS
- PROVISION FOR SEALING
- INTERIOR PRESSURE CAN BE DEPRESSED
- CLEAN EXTERNAL FORM

## K-SERIES DEXTEROUS MANIPULATORS

---

# TORQUE -LOOP SERVO-CONTROL SYSTEM

- FUNDAMENTAL SOLUTION TO INTRINSIC  
HARMONIC DRIVE DYNAMICS  
PROBLEMS
- APPLICABILITY TO ADVANCED  
FORCE CONTROL
- BACK-DRIVABLE FOR TELEOPERATOR  
APPLICATIONS
- POTENTIAL SOLUTION TO MANY  
ACTUATOR TORQUE ANOMALIES

ROBOTICS RESEARCH CORPORATION

ROBOTICS RESEARCH TECHNOLOGY

---

# MODULAR SPACE MANIPULATORS

K-SERIES TECHNOLOGY  
ADAPTED TO SPACE  
APPLICATIONS

- EVA
- IVA

MODULAR SPACE IVA MANUFACTURING MANIPULATOR SYSTEM

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## ASSUMED DESIGN OBJECTIVES

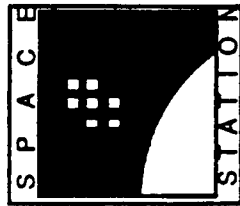
- ADVANCED MANIPULATION CAPABILITY
  - DEXTERITY
  - WORK ENVELOPE VOLUME & ACCESS
  - ACCELERATION / SPEED
  - POSITIONING PRECISION
- SMOOTH MOTION (MICRO-G)
- ACTIVE DAMPING
- FORCE CONTROL / LIMITATION
- SAFE OPERATION
- DESIGN SIMPLICITY & RELIABILITY
- LOW MASS
- ENGINEERED FOR SPACE  
(MICRO-G, VACUUM, THERMAL MGMT, ETC.)
- LOW RISK DEVELOPMENT
- UPGRADEABLE / EXPANDABLE,  
DESIGNED FOR GROWTH

## ROBOTIC WORKSHOP

### Automation In Crystal Growth

Robert Maselsky  
Westinghouse R&D Center  
1310 Beulah Road  
Pittsburgh, PA 15235

Crystal growth requires careful control of heat flow, temperature gradients, positioning, translation, and rotation. The general requirements are applicable to all material systems. The particular requirements are material specific and can vary for the crystal growth technique being utilized. Many of the commercial systems use a differential weight system for automation, a concept not readily adaptable to a microgravity environment. This talk will review some alternative techniques which have been used in oxide and semiconductor crystals. A summary description of optically base automation techniques for Czochralski and dendritic web growth will be presented and concepts for other growth processes suggested.



# Chemical Vapor Transport Experiment (CVTE)

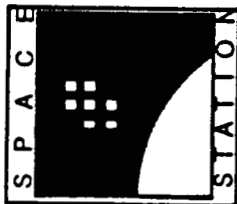
BOEING

A Joint Endeavor between The Boeing Company and the  
the National Aeronautics and Space Administration

C-13

David W. Yoel  
Boeing Commercial Space  
Development Company  
December, 1987

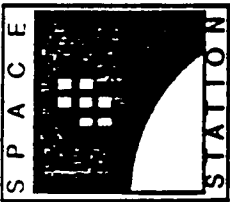




# Joint Endeavor Agreement

BOEING

- Signed May 13, 1986
- No exchange of funds
- 1-2 NASA samples per flight
- 3 middeck/galley flights for initial experiments,  
2 optional flights for scaleup prototyping
- 1st flight tentatively set for STS-35,  
November '89



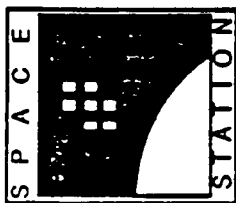
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# Process Technology Objectives

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BOEING

- Develop a reliable method for routinely producing research quantities of high-quality, high value substrates and epilayers in space.
  - Space Shuttle Middeck
  - Spacelab
  - Space Station
- Apply technology developed during space research to better materials production on Earth.
- Develop the capability for tele-operation (remote control) of manufacturing.
  - Industrial Space Facility
- Evaluate future feasibility of production

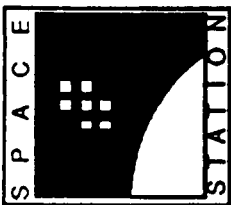


1-011

# Process Technologies Under Development

BOEING

1. Closed tube chemical vapor transport crystal growth - seeded and unseeded.
  - closed system
  - chemical agent assists transport
  - generally used when vapor<sub>2</sub> pressure of source material is below  $10^{-2}$  torr
2. Closed tube physical vapor transport crystal growth - seeded and unseeded
  - closed system
  - transport by evaporation and sublimation
  - used when vapor pressure over  $10^{-2}$  torr
3. Diffusionless - seeded vapor growth
  - partially open system
  - transport agent has forced laminar flow for less turbulence



# Experiment Science Description

BOEING

Vapor crystal growth is a process where polycrystalline source material is vaporized and subsequently condensed as a single crystal

Transparent furnace allows optimization of crystal growth thru in situ observation

Manned - local (Shuttle middeck)

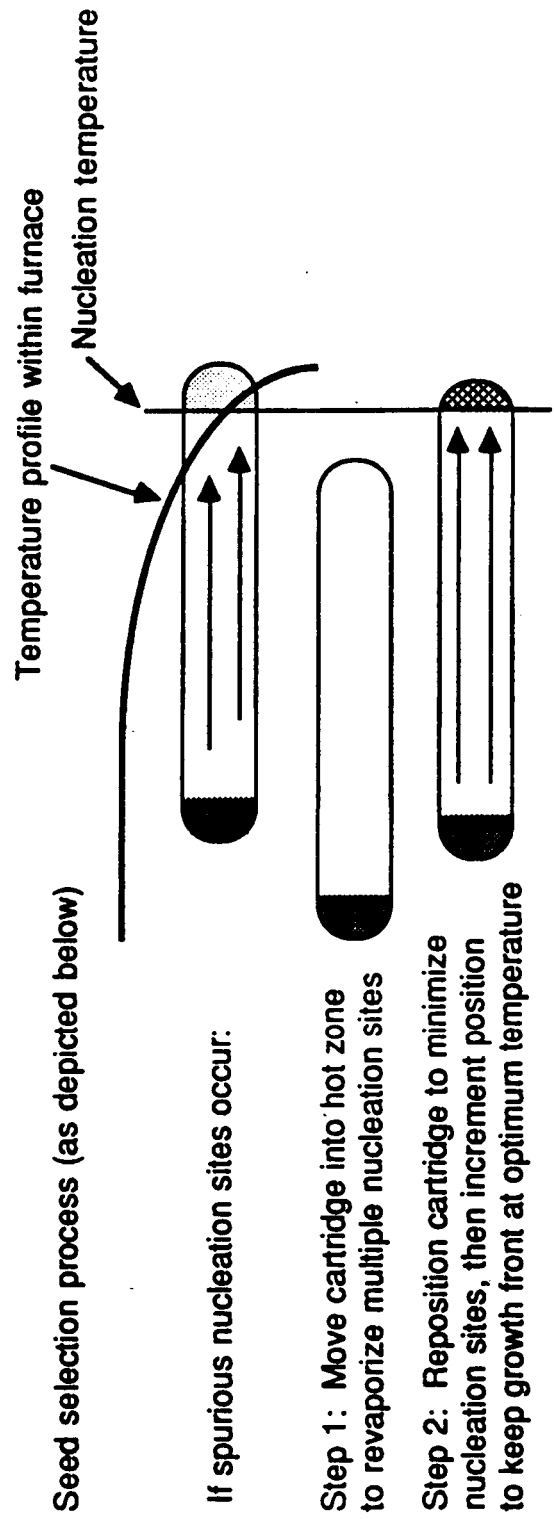
Telescience - remote (Small satellites, Hitchhiker-G, ISF)

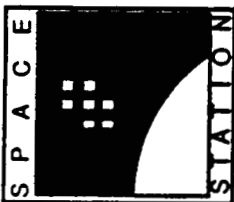
Stationary temperature profile within furnace requires sample positioning for optimal growth

Processing temperatures are from 125°C to 900°C

Growth rates are slow - from 0.01 to 1 gram per day

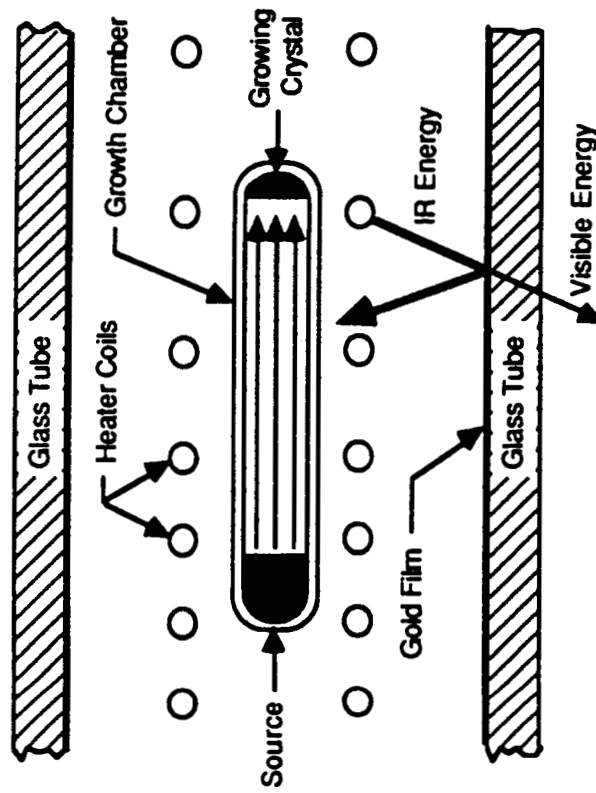
Seed selection process (as depicted below)



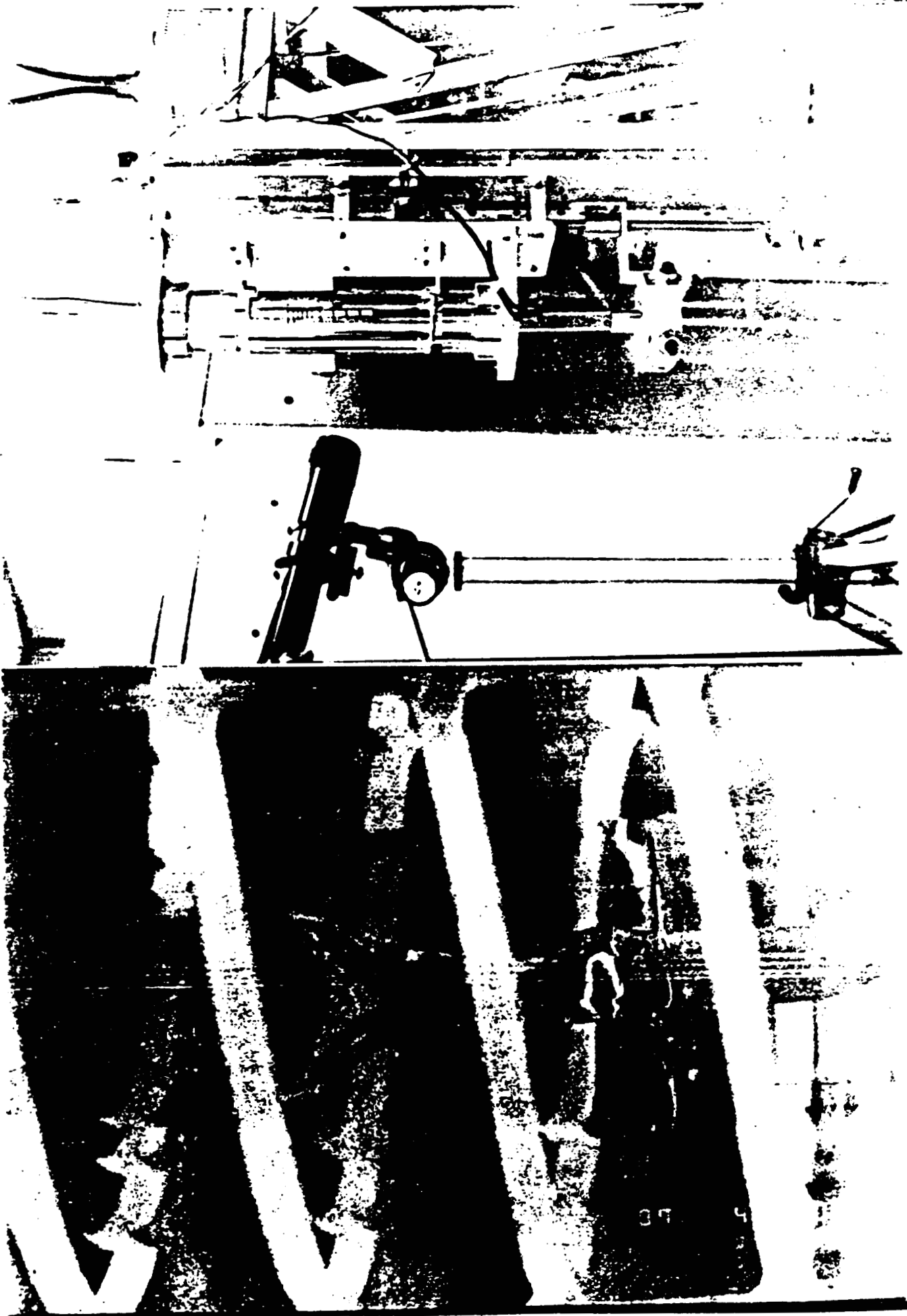


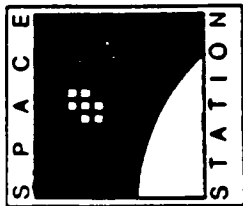
# Transparent Furnace Cross Section

BOEING



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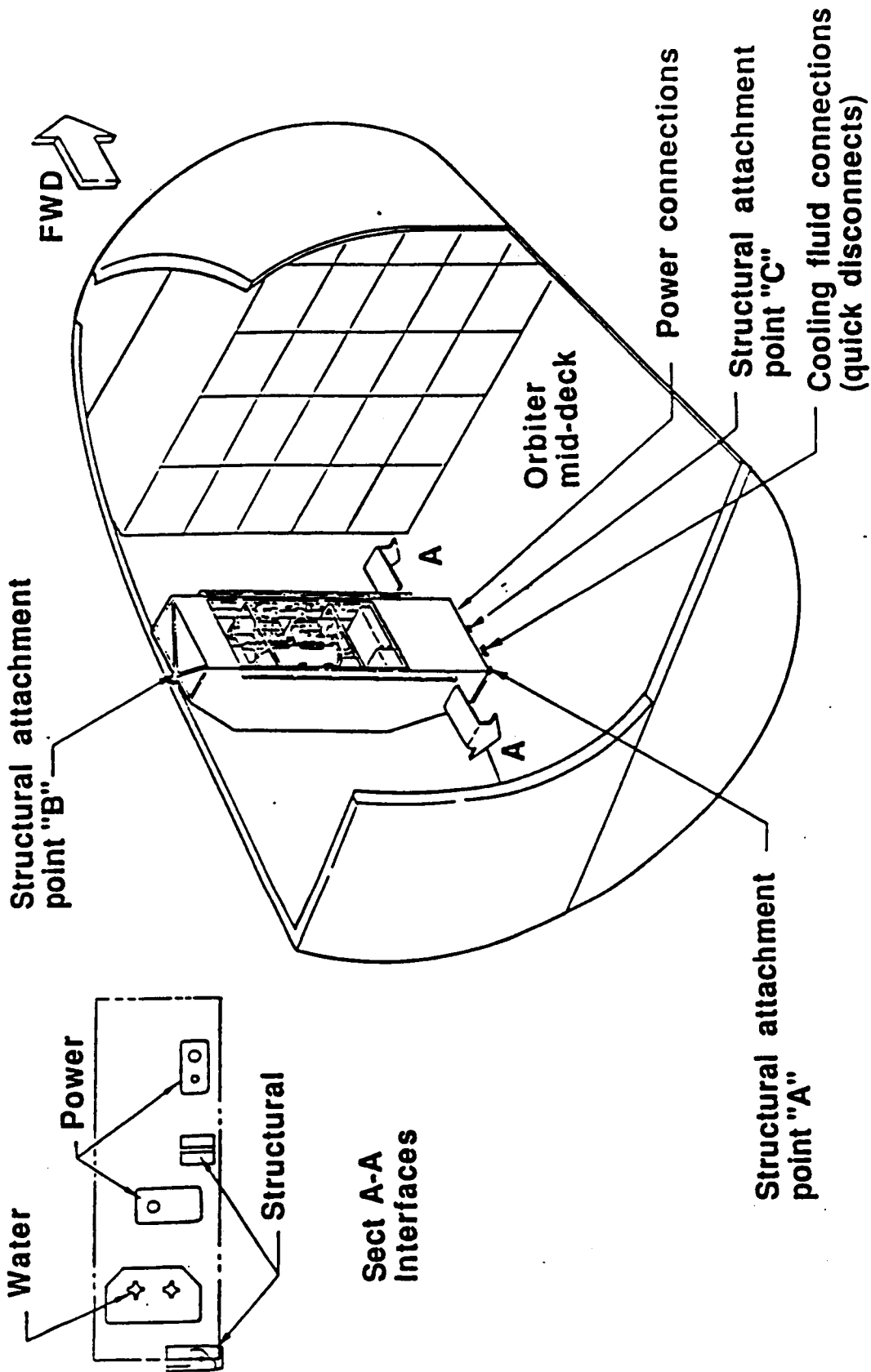


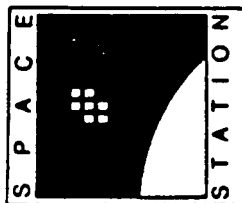
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# Flight Configuration Concept

BOEING



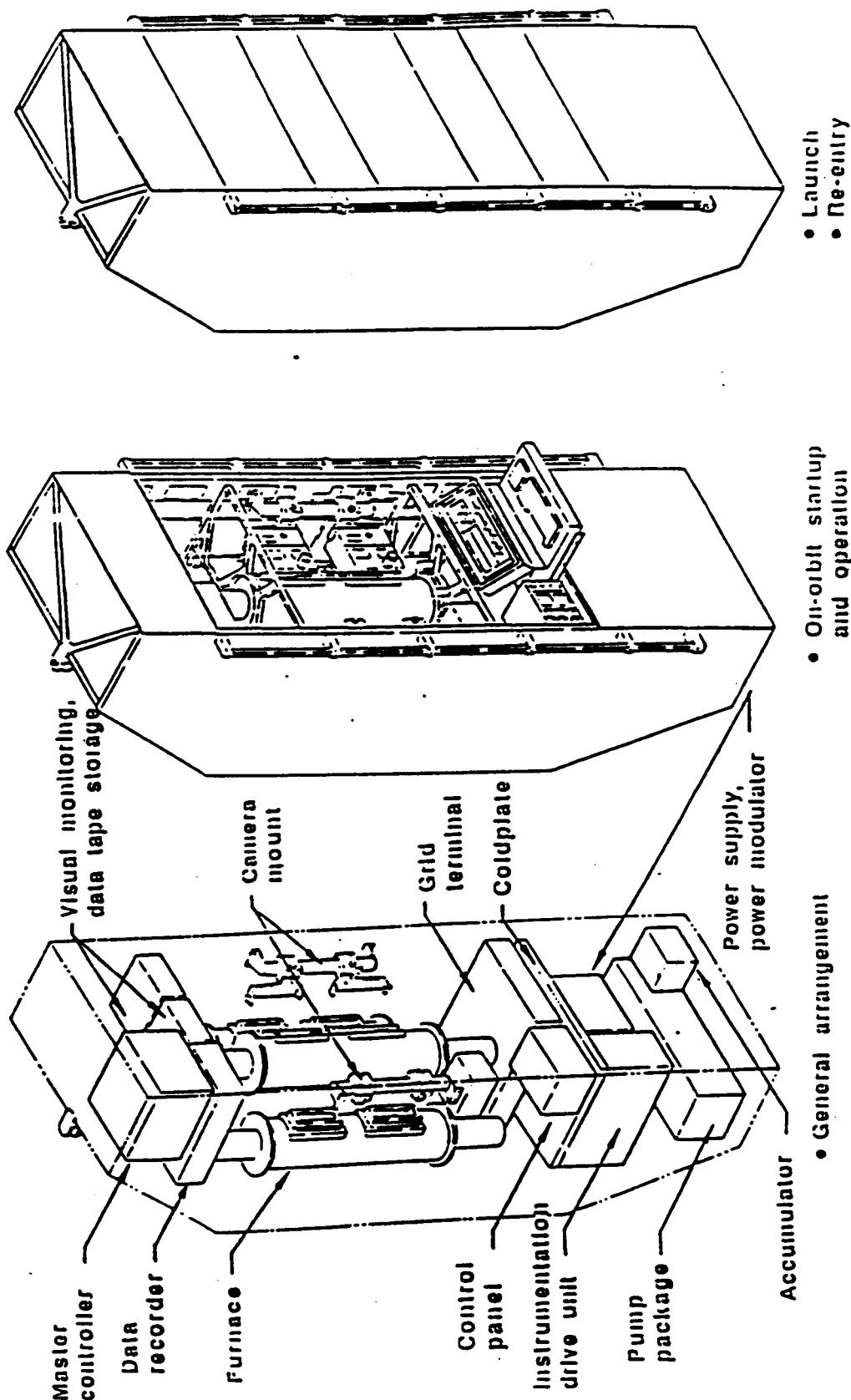


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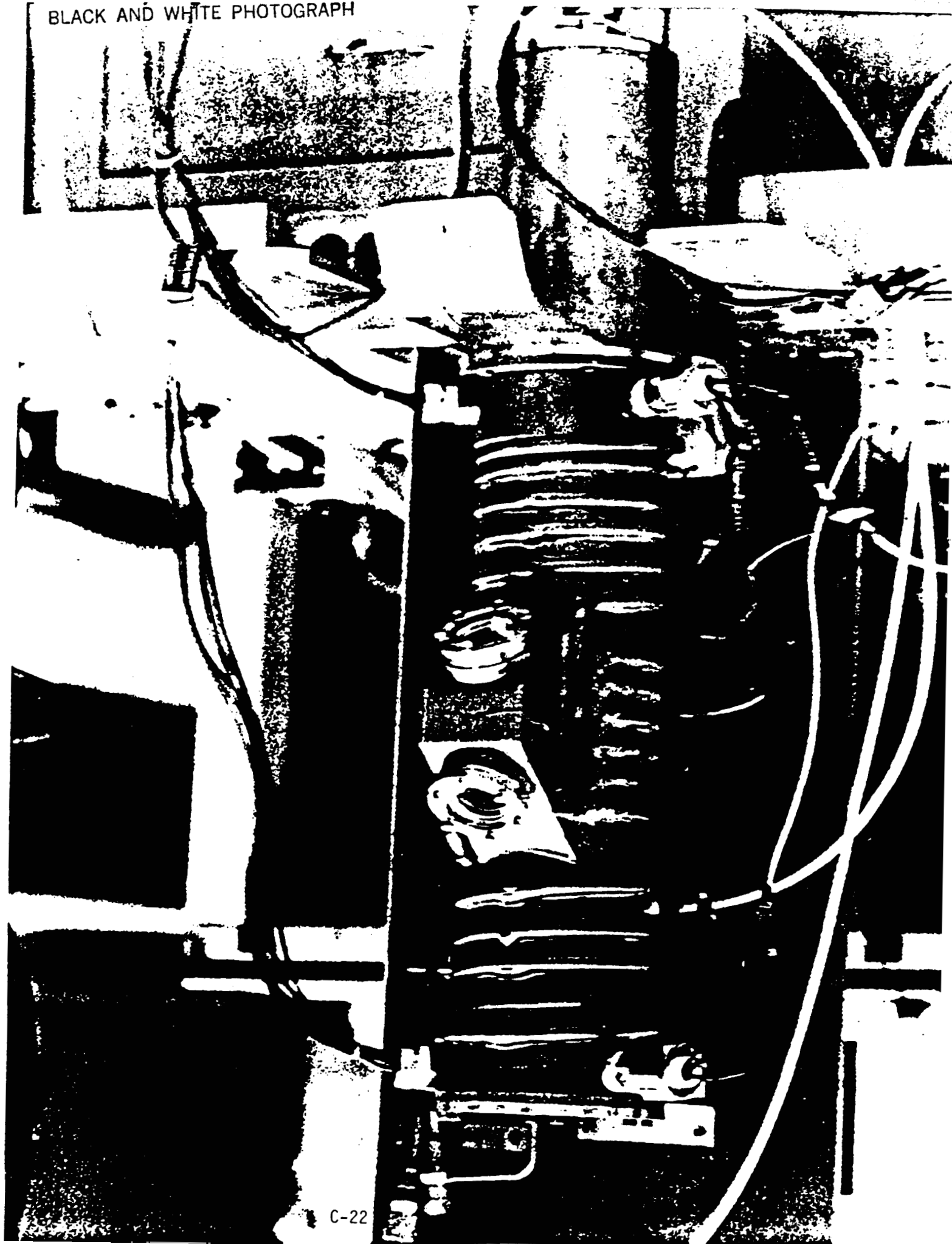
# CVT Flight System

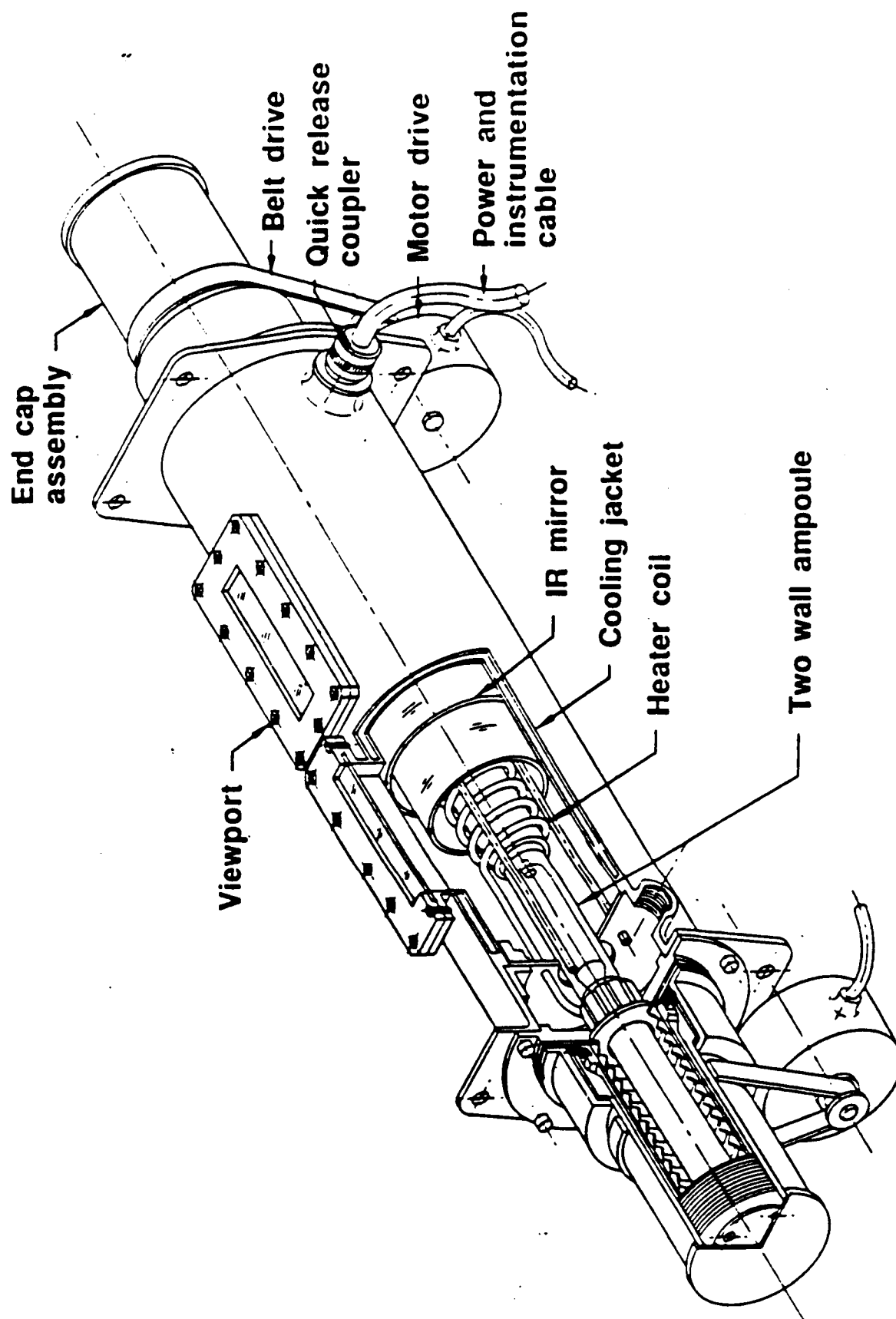
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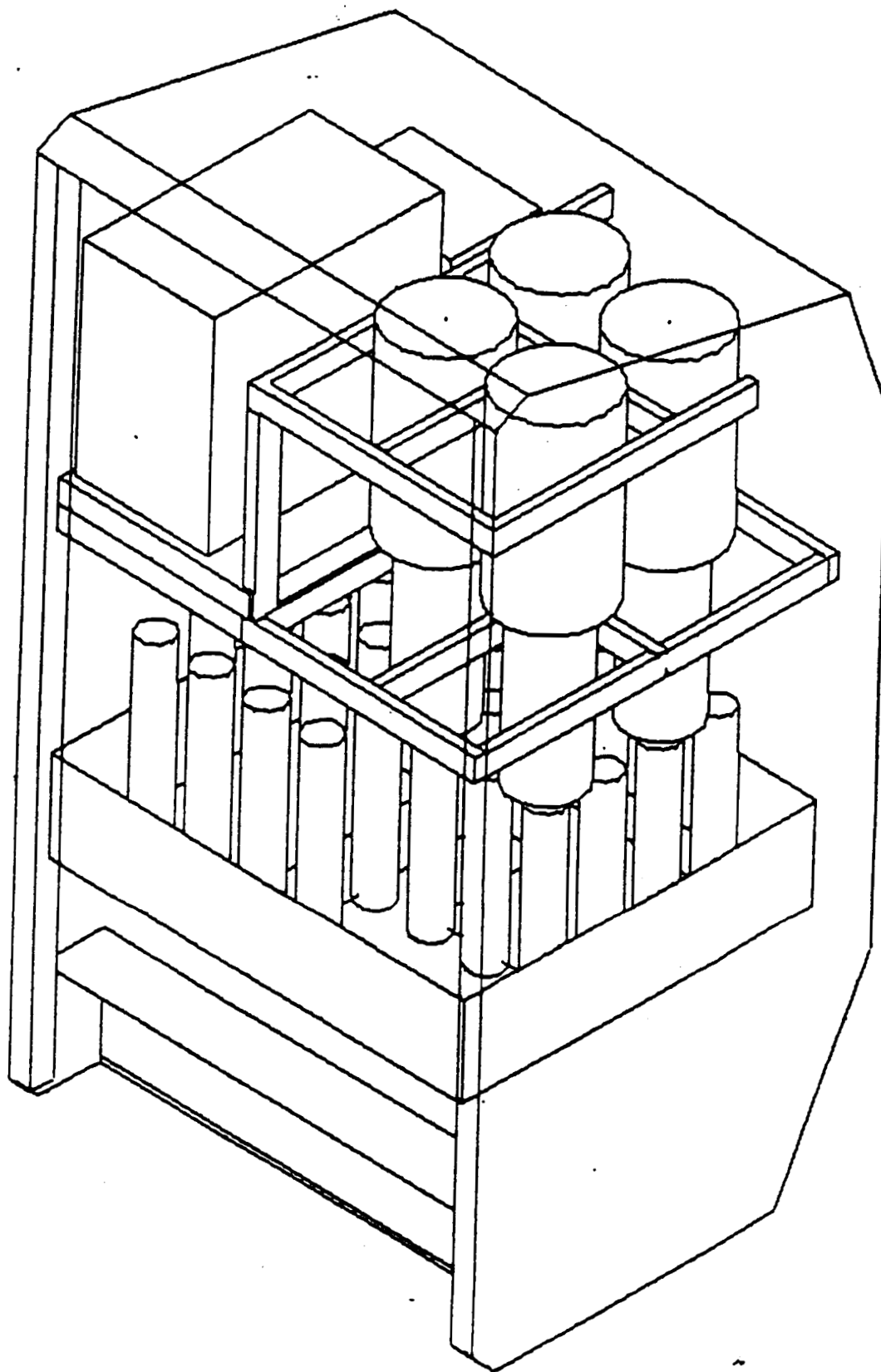
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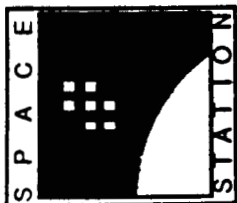




# CVT RACK PACKAGING MODEL

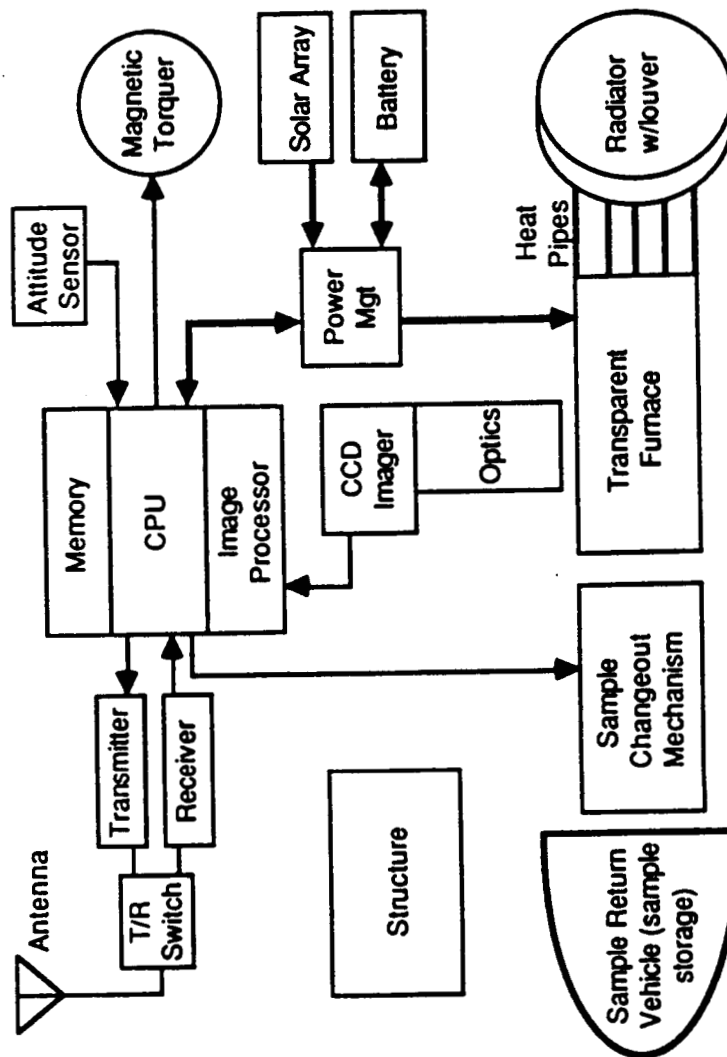
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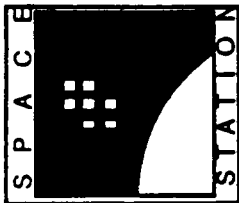




# Small Telescience Freeflyer Block Diagram

BOEING





# Summary

BOEING

- Boeing CVTE experiment tentatively scheduled to fly in manned mode in 2 years
- Man-In-The-Loop increases program efficiency
  - reduces number of flights needed to develop process
- "Man" can be remote, telescience feasible
  - ISF configuration feasible
  - dedicated small spacecraft may be feasible

**Presentation**  
**to**  
**Robotics for Commercial Microelectronic**  
**Processes in Space Workshop**  
**National Aeronautics and Space Administration**  
**Goddard Space Flight Center**

**December 2 and 3, 1987**

**Lisa A. McCauley/Corinne M. Buoni**  
**Advanced Materials Center**  
**for the**  
**Commercial Development of Space**



**Battelle**  
Columbus Division

# **Agenda**

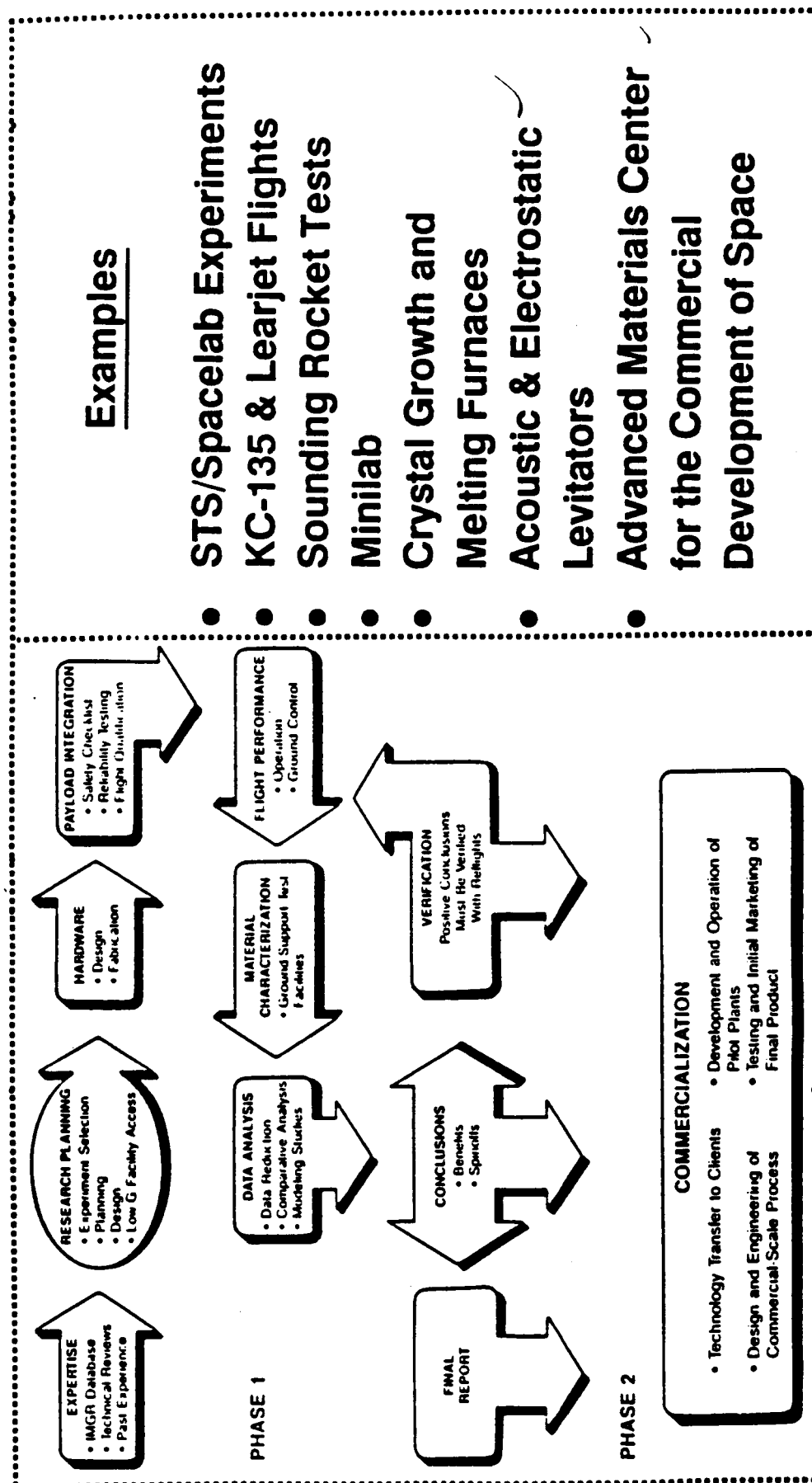


- **Battelle's Current Research Efforts**
  - **Materials Processing in Space**
  - **Robotics**
- **Robotics Applications for Commercial Space Processing:  
Issues and Requirements**

# Our General Capabilities in Microgravity Materials Processing



## Study Results





# **Advanced Materials Center for the Commercial Development of Space**

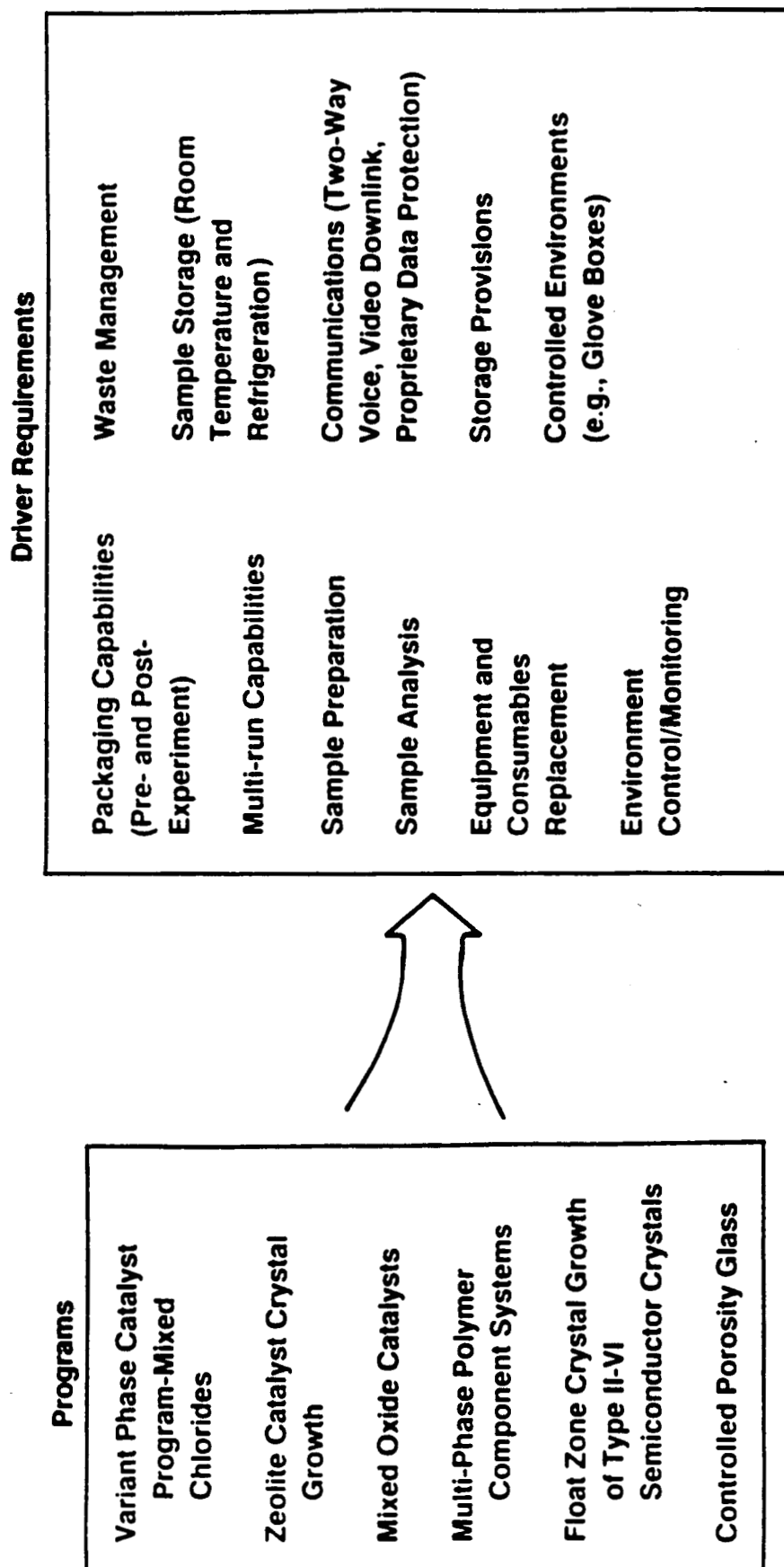


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## **Strategy**

- **Battelle's Strong Technical Areas**
- **NASA-LeRC Strengths**
- **Battelle's Client Base**
- **Generate Grass Roots Technical-Advocacy**
- **Aerospace and Non-Aerospace Industries**
- **Industry Driven Program Directions**

# Battelle's Advanced Materials Center Space Processing Requirements



# **Relevant Robotics Program**



- **Underwater**
  - **Diver Tool Development**
  - **Manipulators and Work Packages**
  - **Support Equipment**
- **Land-Based**
  - **Teleoperated Systems**
  - **Manipulators**
  - **End Effectors and Special Tooling**
- **Space**
  - **Tool Design and Development**
  - **Equipment Design for Microgravity Experimentation**

# Application of Automation and Robotics to Materials Processing Functions



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Materials Processing Functions	Automation and Robotics Technologies													
	Telepresence and Robotics			Sensors		Planning		System Architecture & Integration		Man-Machine Interface				
	Master Control	Supervisory Control	Process Control	Force Sensors	Position Sensors	Machine Vision	Machine Planning	Tolerant Fault	Data and Information	Computer Languages	Subsystem & Process Control	Language Understanding and Visual	Interface Design	Man-Machine Interface
Materials Processing Operations														
Prepare and Load Samples														
Set-Up Apparatus (Nuclei, Seals, Pre-wrap, purge, Calibrate, etc.)														
Initial, Monitor, and Complete Process Run														
Remove and Store Samples														
Set-Up/Complete Additional Process Run														
Shut Down Apparatus														
Prepare & Characterize Samples														
Information and Data Management														
Planning and Scheduling														
Resource Control														
Simulation														
Fault Detection and Repair														
Data Collection														
Data Processing														
Data Transmission, Distribution, and Archiving														
Construction														
Deployment, Erection, and Fabrication														
Assembly														
Servicing, Maintenance, and Repair														
Check-out and Verification														
Inspection and Examination														
Routine Maintenance														
Repair and Configuration Changes														
Contingency and Emergency Response														
Monitoring														
Mitigation														

Anticipated Timeline of Application to MP's Activities © 1987 - 2000

# Automation and Robotics Issues for Commercial Space Processing



- Robot Applications Will Be Mission-Specific
  - Need to Fully Understand Process Operation Before Developing Robotic System to Support Application
  - Specific Applications Will Evolve Over the Next 5-10 Years
- Many Robotic Functions for Space Processing (e.g., Material Transport) are State-of-the-Art for Terrestrial Applications, but Require Further Development and Testing in Space
- Terrestrial and Space Demonstrations Required to Validate Technologies and Systems

- **Process Development**
  - **Astronaut-Tended Experimentation (Set-Up, Process Modification, Product Evaluation, Interaction with PI, etc.)**
- **Near-Term Production**
  - **Process Control Using Hard Automation**
  - **Simple Robotics Systems for Material Handling and Transfer**
  - **Crew-Tended Maintenance and Repair**
- **Far-Term Production**
  - **More Advanced Robotics for Processing, Maintenance, and Repair**

# **Automation and Robotics (A&R) Implementation Plan for Materials Processing in Space**

---



- **Identify and Characterize Space-Based Processes**
- **Identify Candidate Processes and Operations for A&R Applications**
- **Analyze, Synthesize, and Prioritize A&R Requirements**
- **Assess Current and Advanced Electromechanical Hardware and Software**
- **Perform Required Laboratory Research**
- **Construct Earth-Based Test Bed to Evaluate Robotic Technologies and Components**
- **Develop and Evaluate A&R Systems**
- **Perform Flight- and Space-Based Validation Tests (Space Shuttle and/or Space Station)**
- **Integrate Validated Systems into Space Production Facility**
- **Evolve System Complexity and Applications**

**ROBOTICS REQUIREMENTS FOR  
EPITAXIAL THIN FILM GROWTH  
FOR MICROELECTRONICS  
IN SPACE**

**A. IGNATIEV  
SPACE VACUUM EPITAXY CENTER  
UNIVERSITY OF HOUSTON**

**PRESENTATION**

**TO**

**ROBOTICS FOR COMMERCIAL  
MICROELECTRONICS  
PROCESSES IN SPACE WORKSHOP**

**DEC. 2 AND 3, 1987**



**SPACE VACUUM EPITAXY CENTER (SVEC)**

**AT**

**THE UNIVERSITY OF HOUSTON**

**A CONSORTIUM DEDICATED TO THE  
COMMERCIAL DEVELOPMENT OF  
SPACE VACUUM EPITAXY  
TECHNOLOGY**

**UTILIZATION OF SPACE ULTRA VACUUM FOR BOTH  
THIN FILM PROCESSING THROUGH MOLECULAR  
BEAM EPITAXY (MBE) AND CHEMICAL BEAM  
EPITAXY (CBE) AND FOR MATERIALS  
PURIFICATION LEADING TO COMMERCIALIZATION  
OF SPACE**

**PC-1**

## **SVEC GOALS**

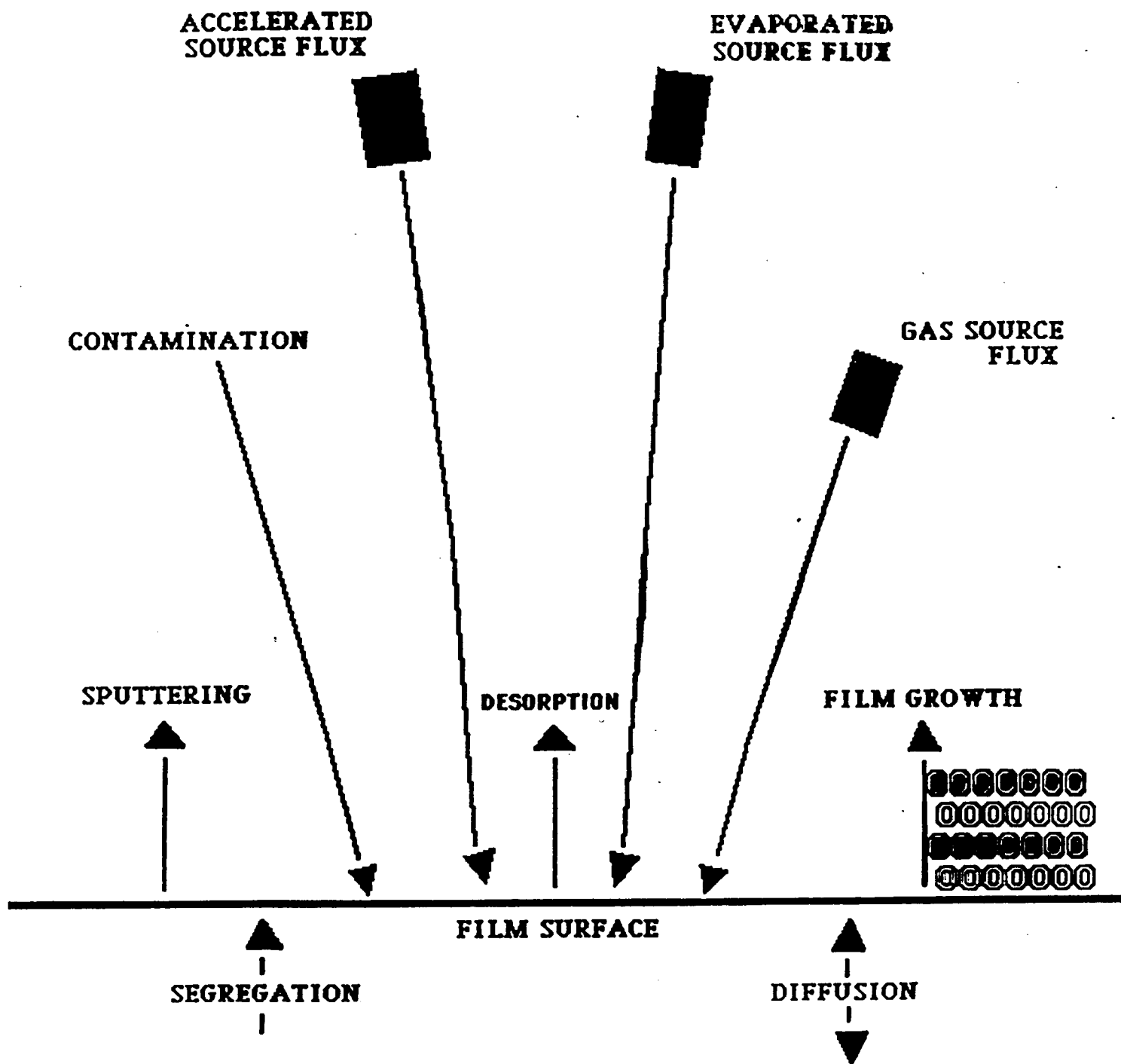
- **To develop Space Research leading to commercial development of LEO ultra-vacuum environments.**
- **Adapt MBE/CBE thin film growth technology to Space ultra vacuum.**
  - **semiconductors**
  - **superconductor**
  - **magnetic materials**

**Can have Major Impact on  
Microelectronics' Industry**

## **Molecular Beam Epitaxy/ Chemical Beam Epitaxy**

- **Epitaxy is a technique of crystal growth through which a material is deposited onto a crystalline substrate in an atom-by-atom manner and the over-all crystallinity is preserved after deposition.**
- **Molecular beam epitaxy (MBE) is a technique for crystal growth by directing beams of atoms or molecules produced by thermal evaporation onto a heated substrate.**
- **Chemical beam epitaxy (CBE) is a technique for crystal growth by directed beams of gaseous molecules which dissociate on a heated substrate.**

## THE PROCESS: MBE/CBE





## **MBE/CBE BENEFITS**

- **PRECISE FABRICATION OF ATOMIC SCALE PERFECT HETERO-STRUCTURES WITH PREDETERMINED DOPING AND COMPOSITIONAL PROFILES MICRO-MATERIALS ENGINEERING**
- **SYNTHESIS OF ARTIFICIAL MATERIALS WITH PRESCRIBED CHARACTERISTICS**
- **NEW DEVICES BASED ON NOVEL PRINCIPLES**
- **NEW SCIENCES**

**MBE/CBE - MOST POWERFUL TOOL IN THE SYNTHESIS OF NEW MATERIALS AND IN THE FABRICATION OF NOVEL MICRO-DEVICES**

PC-6

## **DEVICE APPLICATIONS OF MBE**

- **Opto-electronics (lasers)**
- **Microwave amplifiers  
(low-noise and power)**
- **Millimeter-wave (30 GHz to 100 GHz)  
sources and amplifiers**
- **High-speed digital logic and memory**
- **Thin-film, high-current density, high-  
temperature superconductors**

PC-7

## **EARTH LIMITS ON MBE/CBE**

### **MBE/CBE - A LABORATORY TOOL**

- **SMALL THROUGHPUT - LIMITED CHAMBER SIZE**
- **HIGH BACKGROUND DOPING  
( $10^{14}/\text{CM}^3$ )**
- **INTERFACE CONTAMINATION**
- **SAMPLE NON-UNIFORMITY**
- **WALL CONTAMINATION - ONE MATERIAL MACHINE (NOT SUITABLE FOR EMPIRICAL APPROACH)**
- **SUBSTRATE PREPARATION - CLEAN ENVIRONMENT, DEFECT REDUCTION**
- **TOXICITY OF GASES USED**

**PC-10**



## SPACE ULTRA VACUUM ADVANTAGES

- ULTRA-HIGH VACUUM ( $\sim 10^{-14}$  TORR)
- NEAR-INFINITE PUMPING RATE
- LARGE VACUUM VOLUME WITHOUT WALL
- 4K BACKGROUND RADIATION (SPACE COOLING)
- SOLAR BAKE-OUT
- MICROGRAVITY
- ATOMIC-O
- ATOMIC-H

**ULTRA-VACUUM FACILITY**  
**FOR MBE IN SPACE**

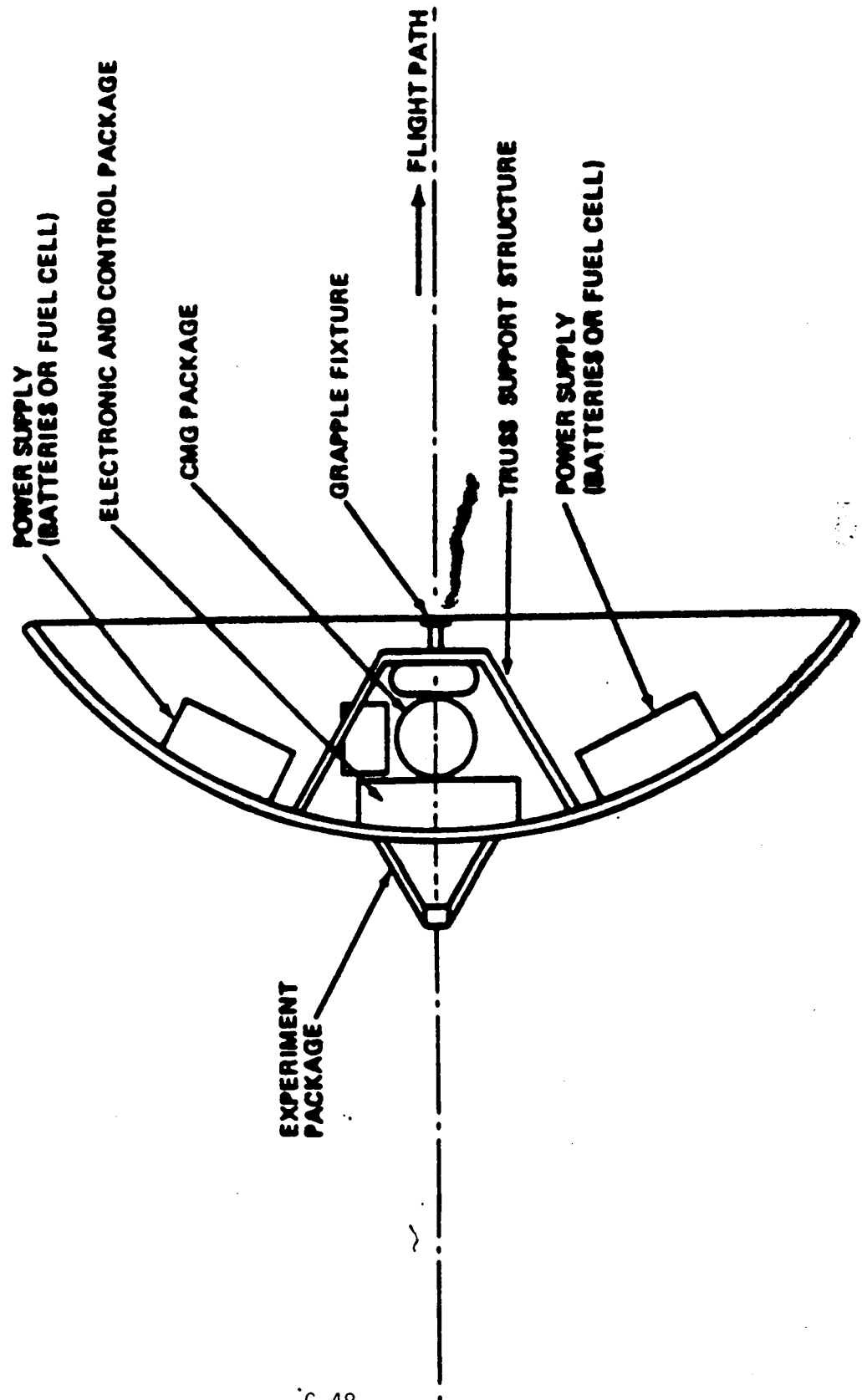
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**\*(SPACE ULTRA-VACUUM RESEARCH  
FACILITY)**

**NASA MARSHALL - INITIAL CONCEPT**

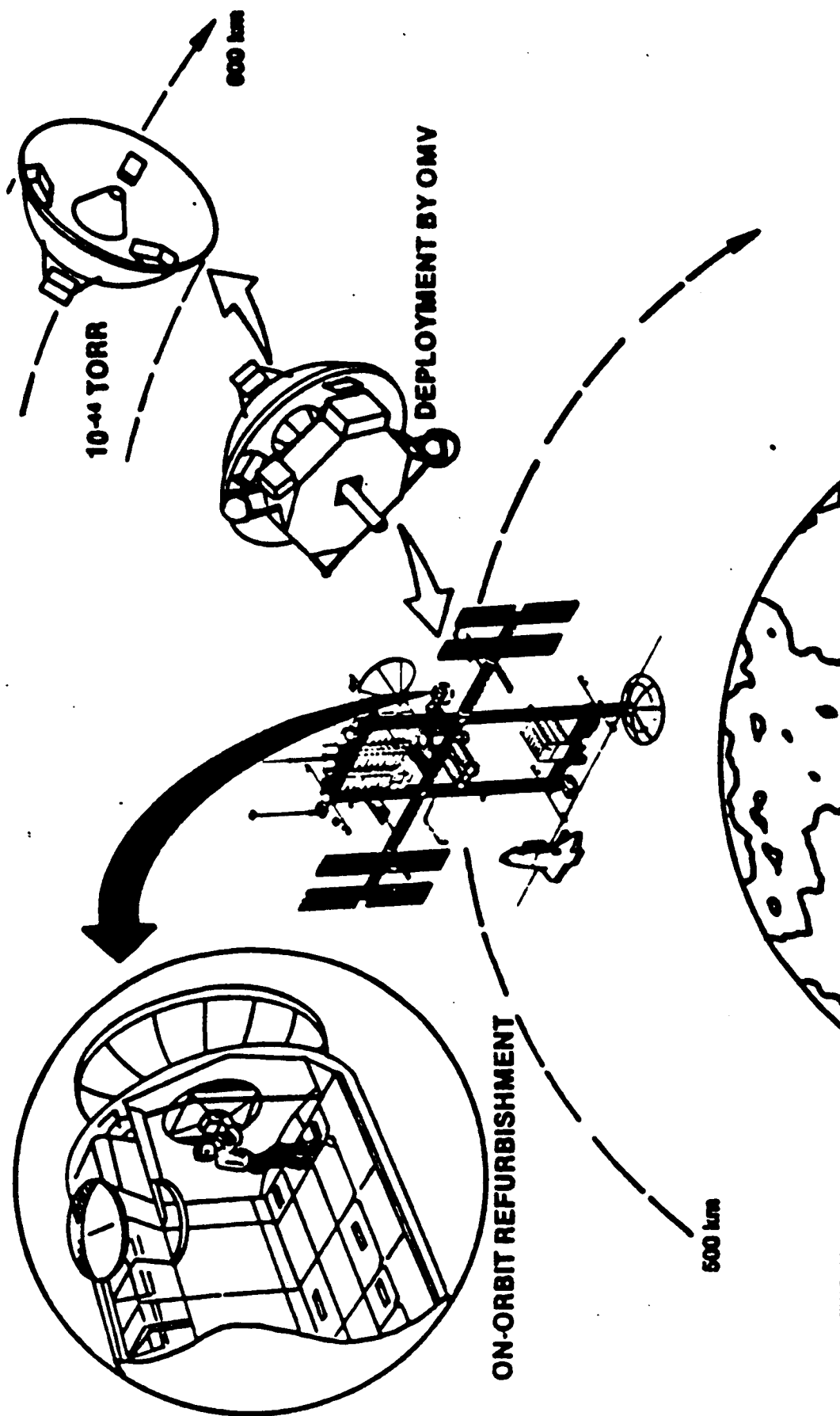
**PC-12**

**SPACE ULTRA-VACUUM FACILITY CONCEPT**



# WAKE SHIELD OPERATIONAL SEQUENCE

(SUPPORTED BY SPACE STATION)



WYLE

# **SPACE VACUUM EPITAXY** **TECHNOLOGY**

## **MBE AND CBE APPLICATION IN SPACE**

- **LITTLE LIMITATIONS ON SUBSTRATE SIZE**
- **NOT MATERIAL SPECIFIC**
  - **ABSENCE OF CONTAINER ALLOWS GROWTH OF MIXED III-V AND II-VI SEMICONDUCTORS AND/OR METAL OR DIELECTRIC (SUPERCONDUCTOR) DEPOSITIONS FOR CONTACT OR PASSIVATION**
  - **HIGH THROUGHPUT** —
- **IN-SITU PROCESSING OF MATERIALS AND DEVICE STRUCTURES**
  - **ION, ELECTRON OR PHOTON BEAMS TO PROMOTE SPATIALLY SELECTIVE GROWTH OR DOPING**

- **ELECTRON BEAM LITHOGRAPHY**
- **ION-BEAM ETCHING**
- **USE OF ATOMIC OXYGEN AND  
HYDROGEN FOR PROCESSING**
- **CONTINUOUS PROCESSING IN  
SPACE, ESPECIALLY FOR  
DEVELOPING RIBBON SUBSTRATE  
GROWTH TECHNIQUE**
- **LARGE ADDED  
VALUE PER UNIT  
WEIGHT**
- **IDEAL COMMERCIAL-  
IALIZATION  
ASPECTS**

**SPACE VACUUM EPITAXY:**  
**APPLICATION EXAMPLES**

**HIGH SPEED TRANSISTORS:**

**Al Ga As**

**In Ga As**

- **X50 to X100**  
**-Faster Than Silicon**
- **X10 Less Power**

**MAGNETO-OPTIC RECORDING**  
**MEDIA (Gd-Y, Gd-Dy)**

- **X10,000 INCREASE IN BIT DENSITY**
- **NO HEAD-MEDIUM INTERACTION**

**THIN-FILM SUPERCONDUCTOR —**  
**THIN-FILM SEMICONDUCTOR**  
**DEVICES**

- **Low Power Dissipation**
- **Increased Response Time**

**SEMICONDUCTOR DEVICES:**

**~ \$35 BILLION/YEAR INDUSTRY**

**MAGNETIC INFORMATION STORAGE:**

**~ \$15 BILLION/YEAR INDUSTRY**

**THIN-FILM SUPERCONDUCTING DEVICES:**

**~ \$\$\$ ???**

**SPACE VACUUM EPITAXY**

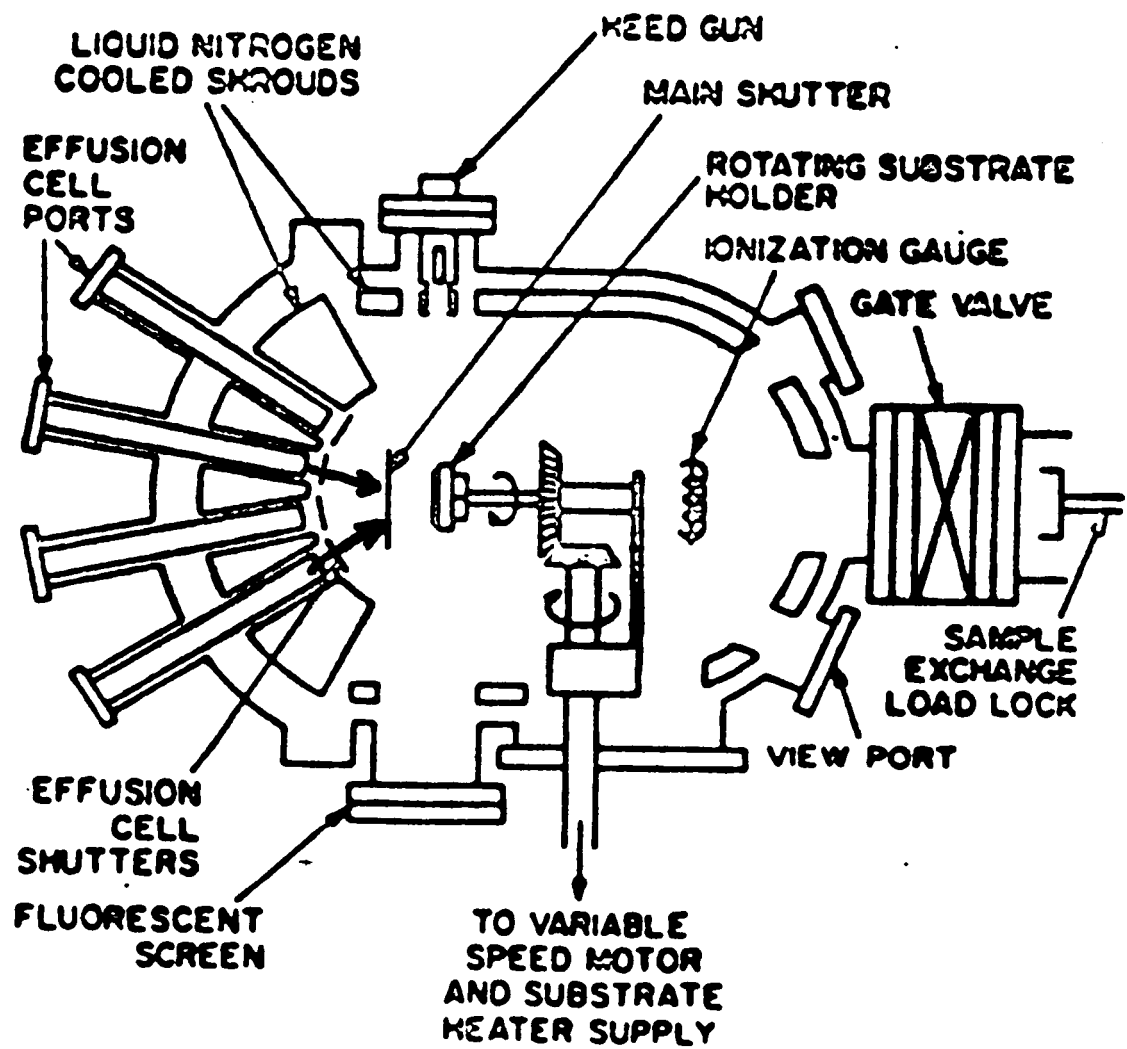
- **Ultra-Vacuum**
- **Large Volume**
- **High Throughput**

**CAN AND WILL MAKE SIGNIFICANT  
IMPACT ON INDUSTRY**

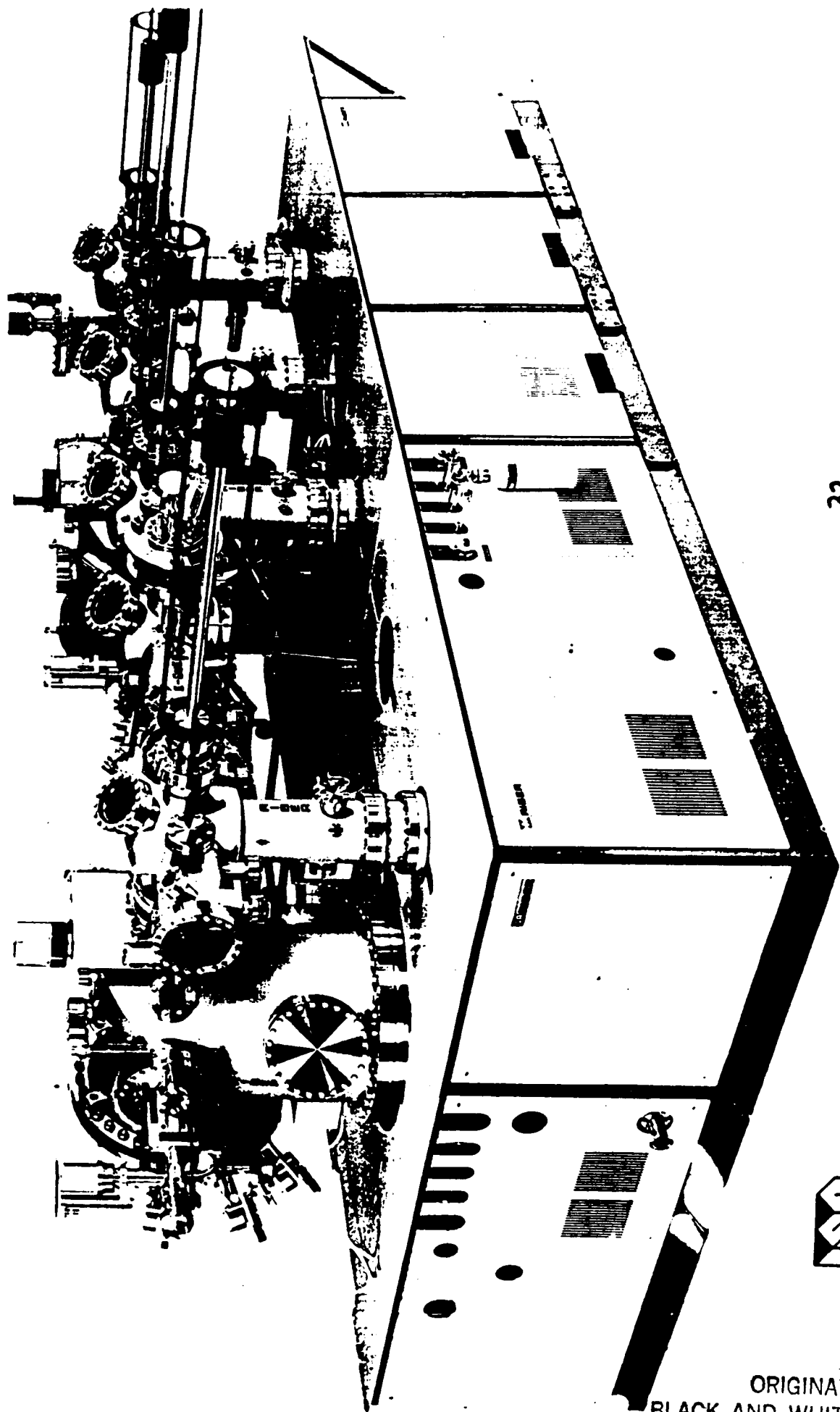


# **ROBOTICS REQUIREMENTS FOR SPACE THIN FILM GROWTH**

- **Robotics applications to be patterned after current manipulation/mobility requirements**
  - **Proof-of-concept experiments**
    - **Substrate sample manipulation**
    - **Mass spectrometer/flux meter manipulation**
    - **Sample transfer & storage**
    - **Effusion cell/gas nozzle changeout**
    - **Gas bottle change out**
- **AI/Expert System control of thin film growth processes**
  - **Complex Growth Profiles**



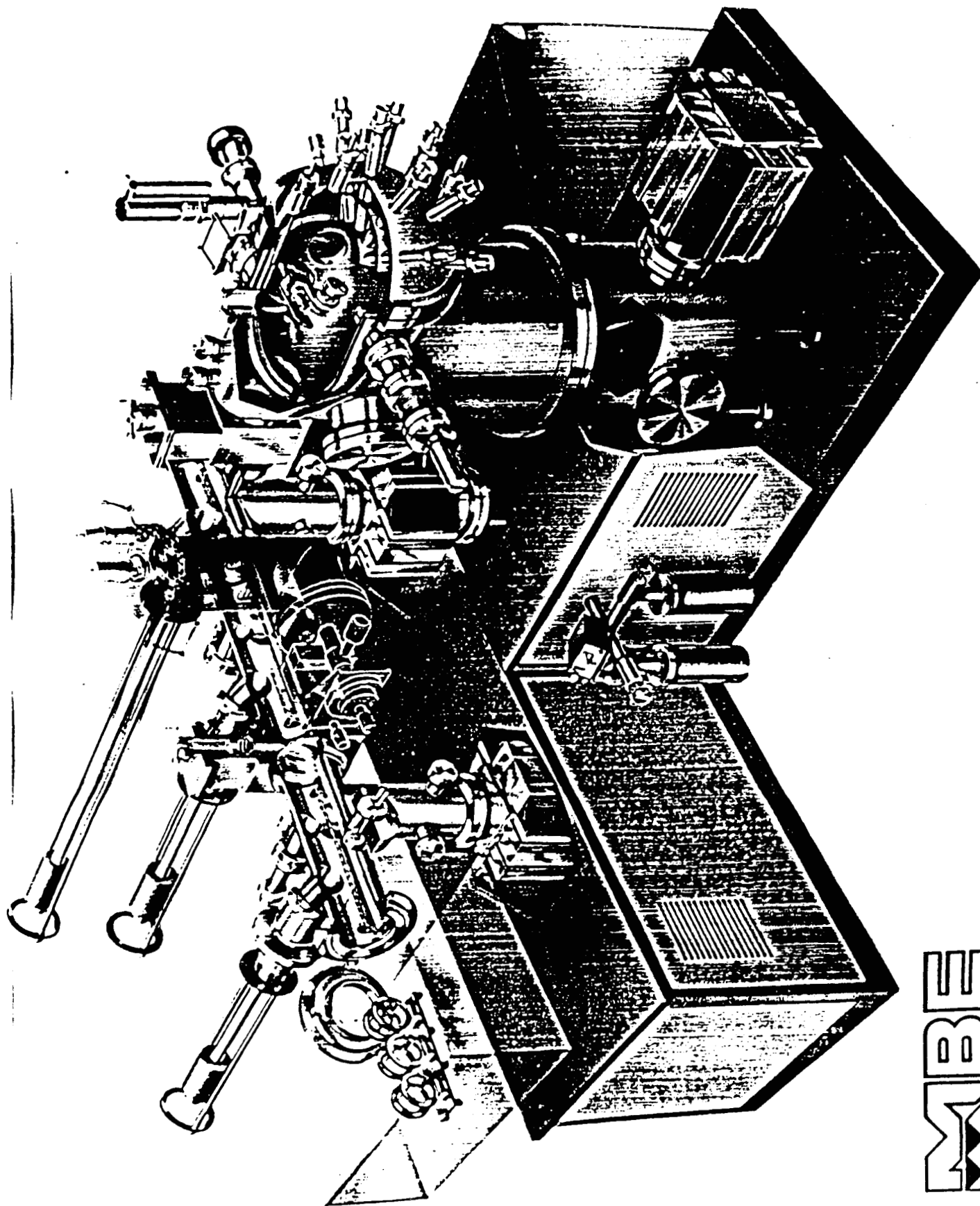
C-2



**ISA RIBER**

32  
**MBE P MODUTRAC®**

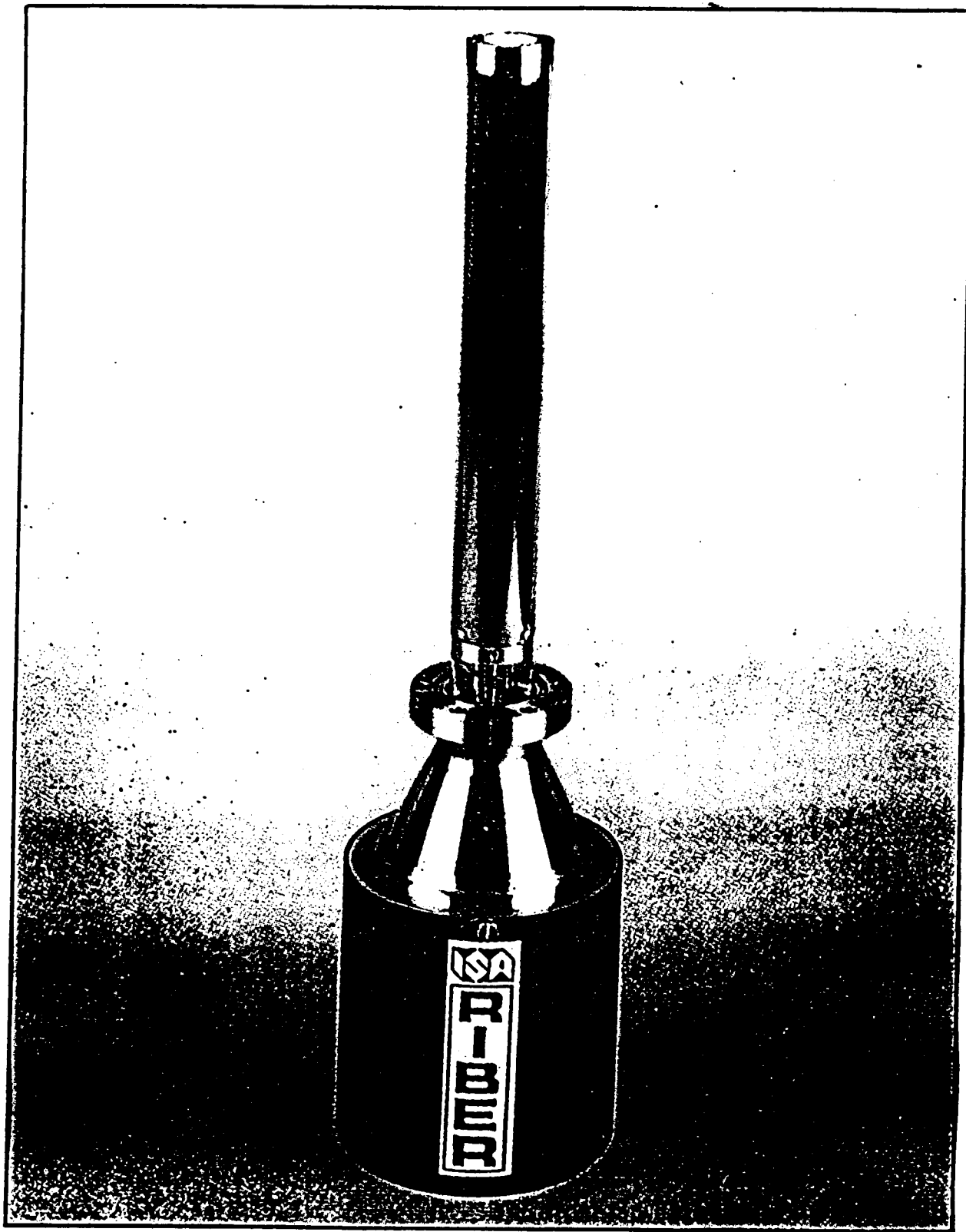
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MBE 2300 P MODUTRAC®

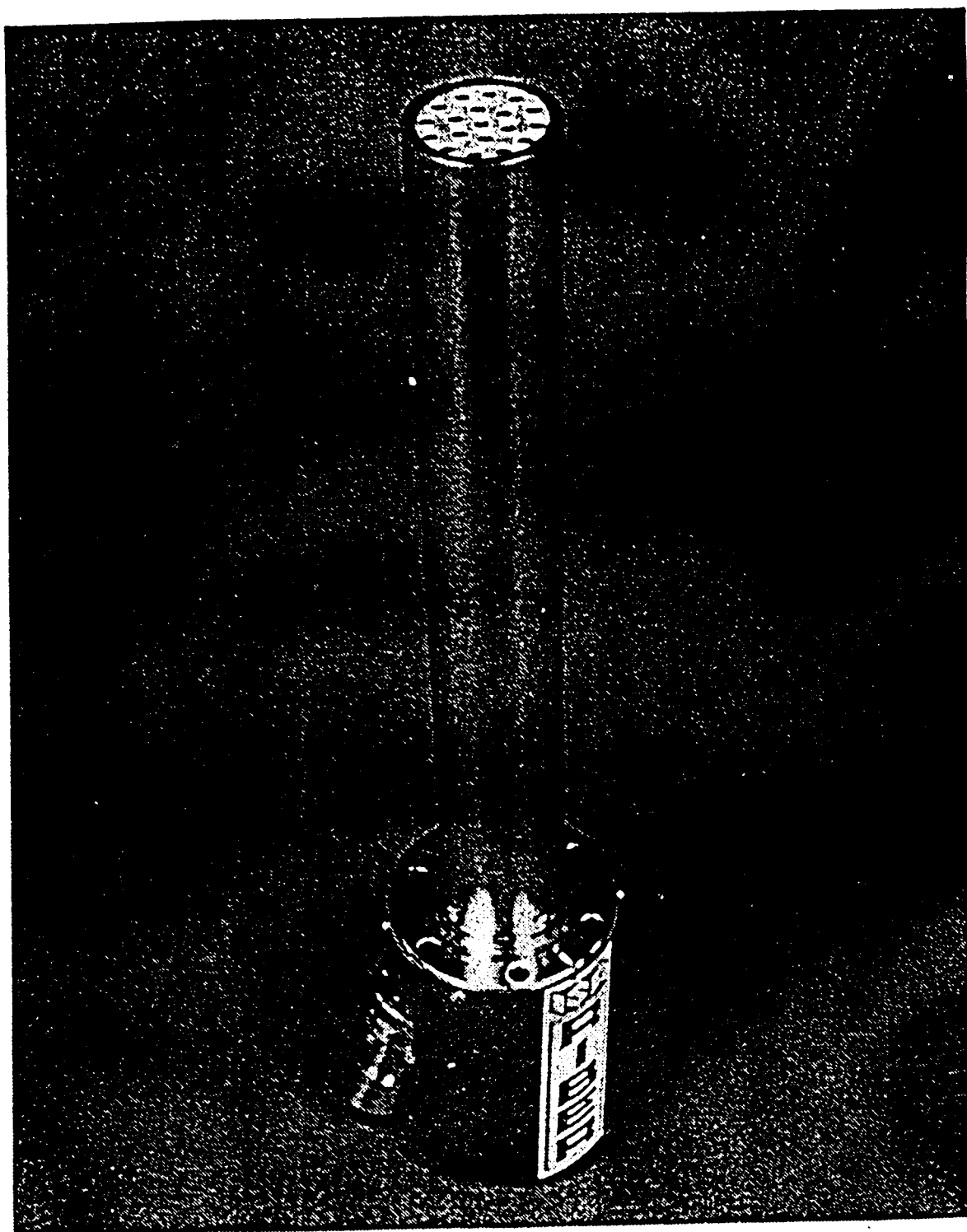
**MBE**  
**SA RIBER**  
DIVISION INSTRUMENTS S.A.

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PBN Cracker Cell

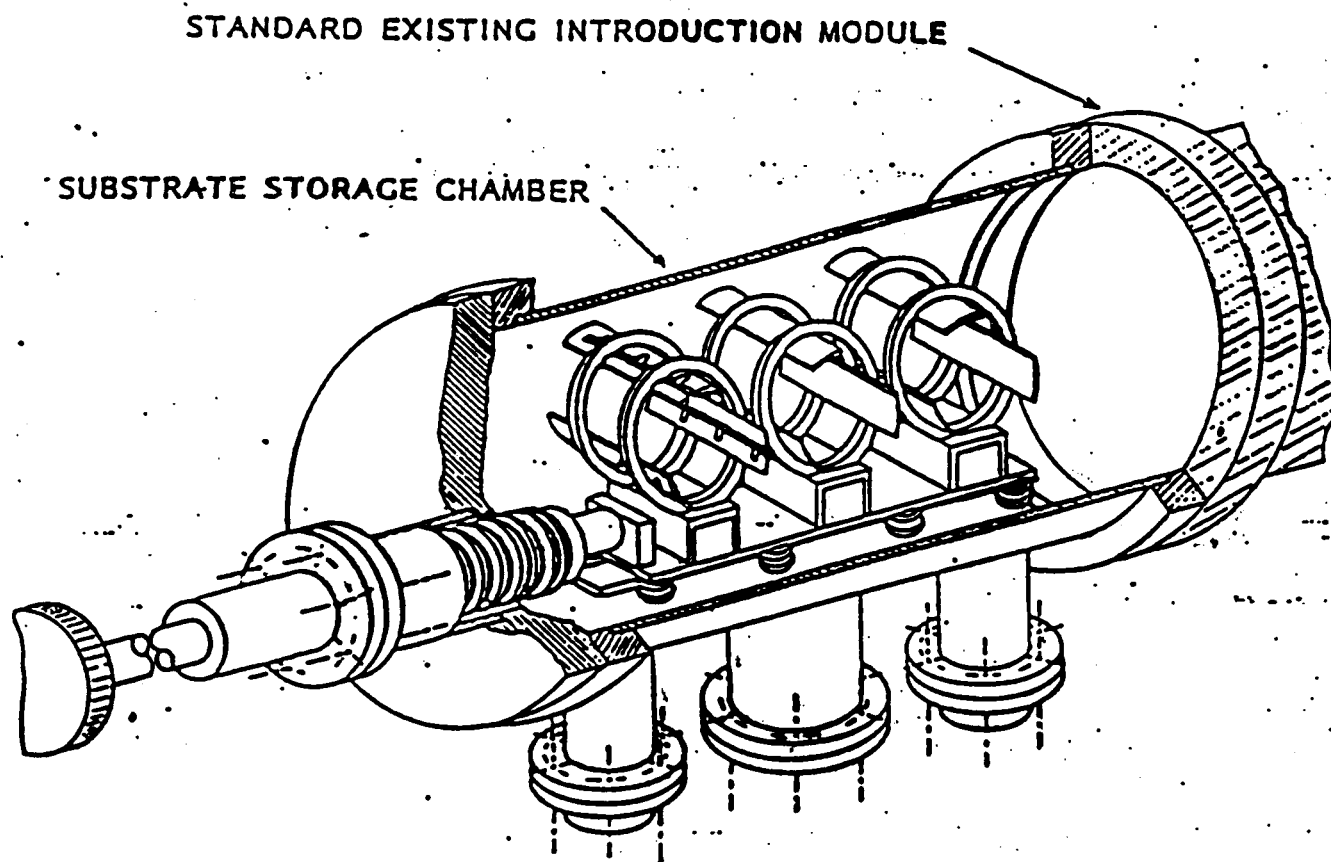
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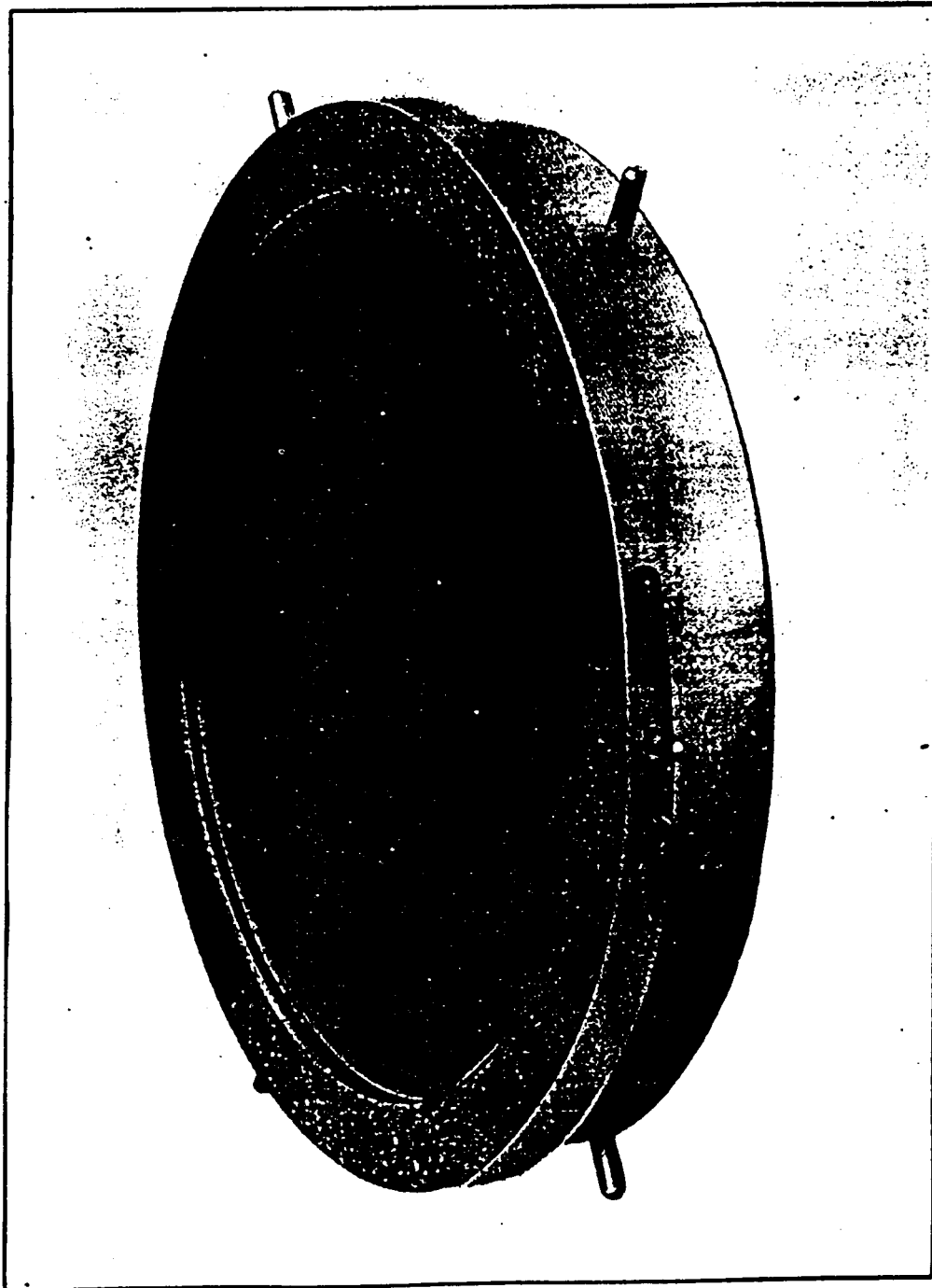
# SUBSTRATE STORAGE CHAMBER



- PERMITS TO INTRODUCE UP TO 30 WAFERS
- REQUIRES NO ADDITIONAL PUMPING
- EASY TO INSTALL ON ALL MODUTRAC LINE
- CAN BE INSTALLED AT BOTH ENDS OF A MODUTRAC LINE

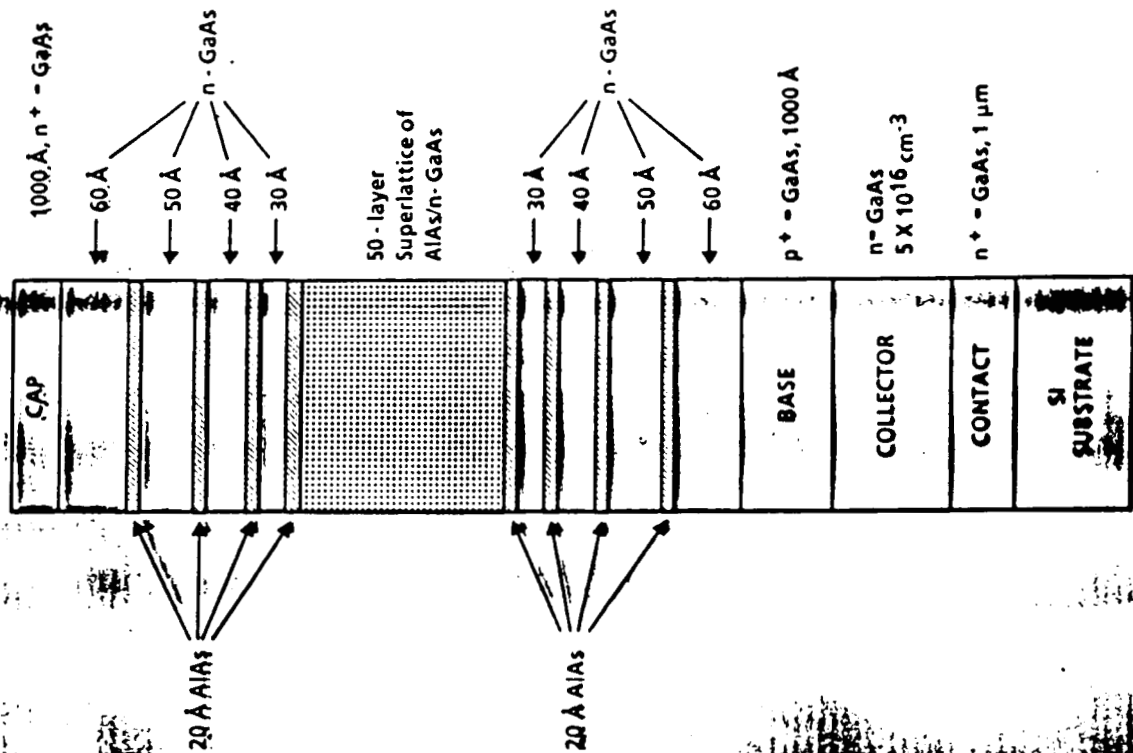


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*This very simple indium-free substrate holder  
(here 3") saves time and improves yields*

# ARTIFICIALLY STRUCTURED MATERIALS SUPERLATTICE HETEROJUNCTION BIPOLAR TRANSISTOR



## IV CHARACTERISTICS

- SUPERLATTICE PROVIDES EFFECTIVE BANDGAP GRADING
- ORDERS-OF-MAGNITUDE REDUCTION IN CURRENT DENSITY (LOW POWER)

STRUCTURE

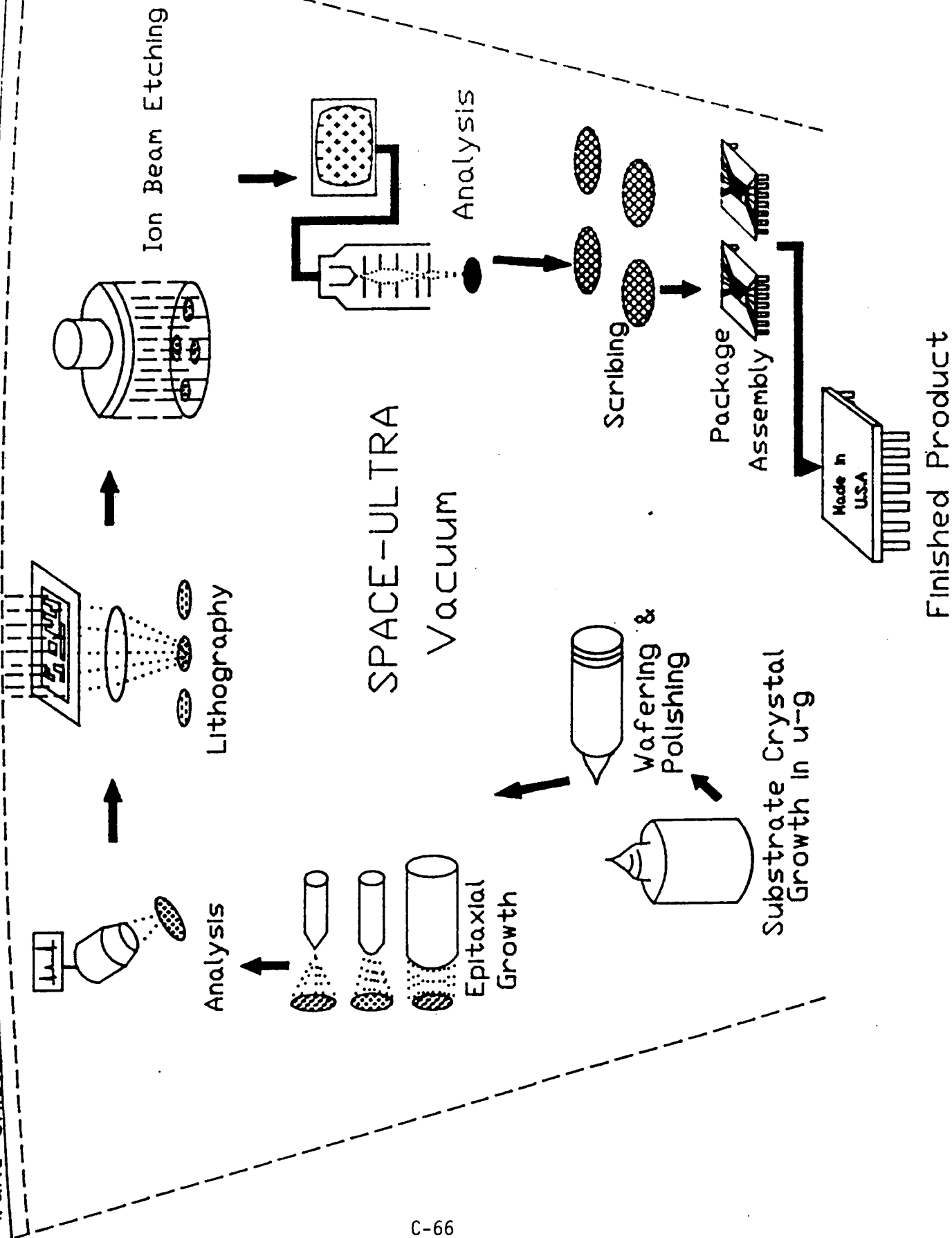
- **Future Commercial Needs**

- **Production Applications**

- **Substrate preparation - wafer formation**
    - **Wafer transport & cleaning**
    - **Epitaxial growth - real time control with feedback**
    - **On-line analysis**
    - **Lithography**
    - **Etching**
    - **Analysis**
    - **Metalization**
    - **Scribing**
    - **Packaging**

# MBE/CBE PRODUCTION LINE IN SPACE

Wake Shield



**IC MANUFACTURE IN VACUUM**

**THOMAS E. SEIDEL**

**UNIVERSITY OF CALIFORNIA**

**CRSM-CENTER FOR ROBOTICS IN MICROELECTRONICS**

**SANTA BARBARA, CALIFORNIA 93106**

**(805) 961-4970**

**TES 12/2/87**

## **MEETING A SPECIAL NEED**

**->PROFILARATION OF ASIC, CUSTOM IC'S**

**HOW BEST TO DO DESIGN VERIFICATION?**

**WANT:**

**FAST TURN AROUND**

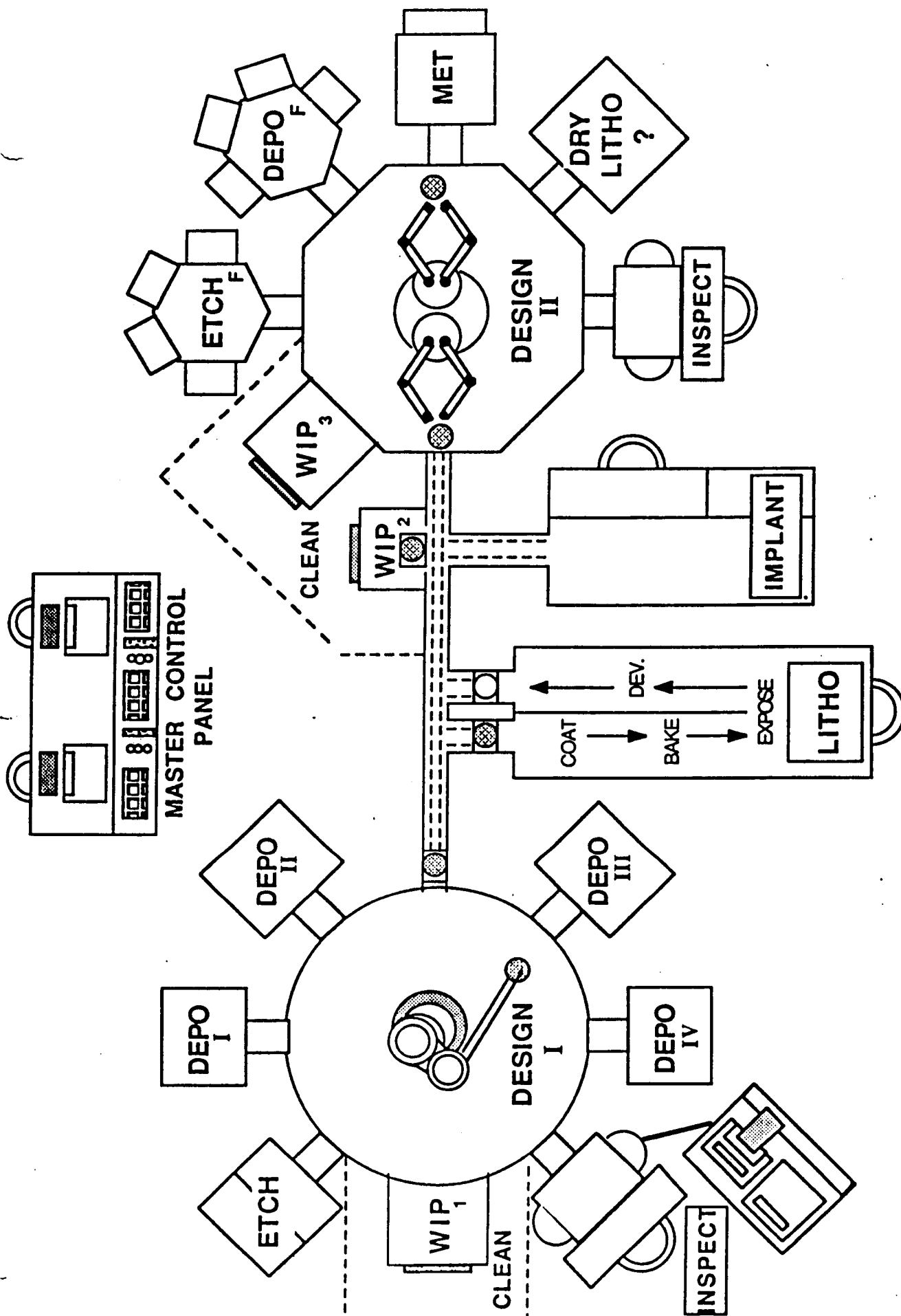
**HIGH YIELD (VACUUM INTERFACING)**

**SMALL FOOTPRINT - LOW COST**

**PROCESS (SERIAL) CONSOLIDATION**

**SENSOR TECHNOLOGY DEVELOPMENT**

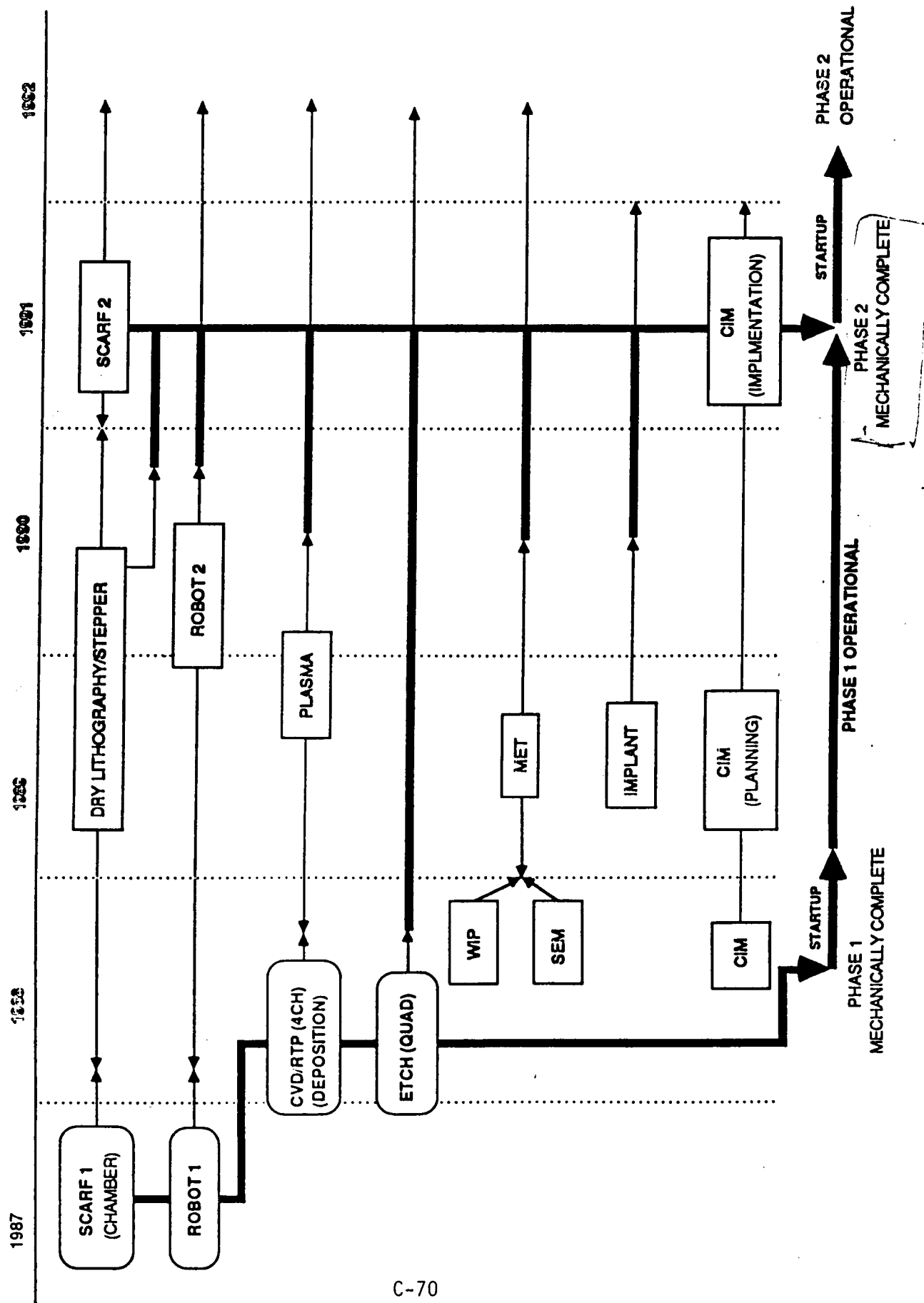
**TES 12/2/8**



PKS  
8/28/87

# IC SYSTEM CONFIGURATION

# CRITICAL PATH (FACILITIES)





# **PATH FOR PROOF OF CONCEPT**

**GUIDELINES:**   **WAFERS TO STAY WITHIN SCARF AS LONG AS**  
**PRACTICAL,**  
**AND WE PRACTICE THE IDEA OF**  
**PROCESS CONSOLIDATION**  
**"TWO-FERS"**  
**SEQUENTIAL OPERATIONS IN THE SAME TOOL**

**(MOVIE -TO FOLLOW)**

**PROPOSED:**   **NMOS (SHORT) 4 mask PROCESS: "kTMOS"**

**(POLY GATES**  
**(\*SIDE WALL OXIDE SPACERS**  
**(DIFFUSED SELF ALIGNED SOURCE & DRAINS**  
  
**\*POLY-CIDE CONTACTS / RUNNERS**

**TES 10/22/87**

# S.C.A.R.F. SHORT NANOSECOND PROCESS

P<sup>+</sup> ( $5 \times 10^{16} / \text{cm}^3$ )

THICK OXIDATION (Dry/ Deposited/ RTA Densification) — N6K

EXIT: PHOTOLITH: THIN OXIDE

ETCH/ STRIP/ CLEAN — DTK  
 GOX/ DOPED POLY — N6K

EXIT: PHOTOLITH: POLY

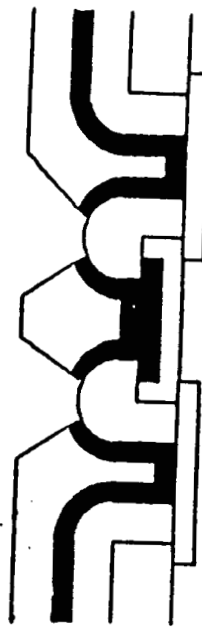
ETCH/ STRIP/ CLEAN — DTK  
 DEP SIDE WALL OX — N6K  
 ETCH — DTK  
 DEP DOPED POLY/ RTA — N6K  
 ETCH POLY — DTK  
 DEP BPSG/ FLOW RTA — N6K

EXIT: PHOTOLITH: CONTACT

ETCH/ STRIP/ CLEAN — DTK  
 REFLOW RTA — N6K  
 DEP DOPED POLY/ TUNGSTEN, W METAL — N6K

EXIT: PHOTOLITH: METAL

ETCH/ STRIP/ CLEAN — DTK



# SCARF DRIVERS: CYCLE TIME, YIELD

STILL, A KEY ISSUE FOR COMMERCIALIZATION:

## VOLUME THROUGH-PUT

PRELIMINARY ESTIMATES FOR AN 8- MASK CMOS PROCESS  
(ASSUME: JUST-IN-TIME, INSPECTION = PROCESS TIME)

# WAFERS/"LOT"	1	4	8	16
TURN AROUND TIME (hrs)	24	44	83	160
#wafers/day	1	2	<3	>2
#wafers/yr	300	600	<900	>600
#lots/week	6	3	2	1
#lots, <u>#designs/yr</u>	300	<u>150</u>	<u>100</u>	50

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# **PROCESS RESEARCH**

## **STRATEGY**

**MODEL 0.5uM PROCESS/ RUN 2uM-4 MASK**

**PRACTICE "PROCESS CONSOLIDATION"**

**EXPERT DIAGNOSTICS-YIELD, CYCLE TIME**

**PROCESS TOOL EXPERIMENTS (AUTOMATION/CONTROL)**

**CVD: *Oxlnitridation*, deposited ox, nit...**

**ETCH: Damage, cross contamination**

**DRY LITHOGRAPHY / (1988 REV)**

## **PARTICULATES**

**LAMINAR FLOW GLOVE BOX TO WIP TO INSPECTION  
*AUTOMATED PUMP CYCLE*; LOAD LOCKING**

**GETTERING USING ELECTROSTATICS**

**INTRINSIC GENERATION IN CVD, ETCH**

# **SENSORS**

## **INTELLIGENT MACHINE RESEARCH**

### **METROLOGY WILL LEAD TO CLOSED LOOP CONTROL\***

#### **THICKNESS MONITORING\* --EXISTING CRSM PROJECT**

**Color Vision Analysis**

**Ellipsometry**

**Spectral Analysis of reflected light**

#### **LINE WIDTH MEASUREMENT\* --EXISTING SOLID STATE PROJECT**

**Heterodyning Optical**

**SEM or optical equivalent**

#### **TEMPERATURE MONITORING\*-- TO BE IMPROVED HERE**

**Pyrometry**

**CCD**

#### **PARTICULATE MEASUREMENT**

**(unpatterned wafers)**

**--RECOMMENDATIONS FOR OPERATIONS**

**--SOURCE IDENTIFICATION, CONTROLS**

#### **DEFECTIVE PATTERN RECOGNITION**

**--> (LONGER RANGE FOR CRSM)**

**(patterned wafers)**

**Optical Processing**

**Holographic Techniques**

#### **WAFER FLATNESS**

**Proximity**

**Laser Scanner**

#### **NEAR SURFACE QUALITY**

**OBIR**

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## **IMPLICATIONS OF SCARF**

**FASTER TURN AROUND**

**X 3-15**

**HIGH YIELD**

**CLASS 0.1**

**LOW COST**

**\$4M/factory?**

**FLEXIBLE PROTOTYPE FACILITY**

### **RESEARCH & EDUCATIONAL**

**Automated Closed Loop Control in:**

**CVD, Etch, Dry Litho**

**Sensor Technology**

**Robotics (levitation)**

**Particulates**

**Vacuum Engineering**

**IC Process Architecture, ( eg kTMOS)**

**Expert Systems**

**Queing Theory**

### **OEM TEST BED**

**Robots, Depos, Etch, Sensors**

### **CHEM SUPPLY**

**New Chemicals for fast depos, etches**

### **IC INDUSTRY INTERFACING**

**ASIC Houses**

**TES 9/3/87**

## SCARF RESOURCE SUMMARY

	EXP	CAP
NSF(PROPOSED)	60%	30%

UCSB  
DARPA  
SRC  
SEMATECH

ALL OEMS (NANOSIL, DRYTEK, YASKAWA, JCSCO...)  
IC MFRS (AT&T, SANDIA...)

CA MICROS  
NASA

## SCARF CAPITAL MAJOR ITEMS

ETCHER	1988	110K
LITHO	1989	100K
IMPLANT/MET	1990	130K/60K
ADV.ROBOT	1991	75K
CIM/SENSORS	1992	75K/50K

# ROBOTICS FOR COMMERCIAL MICRO-ELECTRONIC PROCESS IN SPACE

Neville Marzwell  
Jet Propulsion Laboratory  
(818)354-6543



## ISSUES

FUNDAMENTAL FUNCTIONS PROVIDED BY ROBOTS

ROBOTIC SERVICES USEABLE IN SPACE MICROELECTRONIC LABS

ASPECTS OF SPACE WHICH INFLUENCE ROBOTS

TECHNOLOGY DEFICIENCIES

ROBOTICS CAPABILITIES IN SPACE

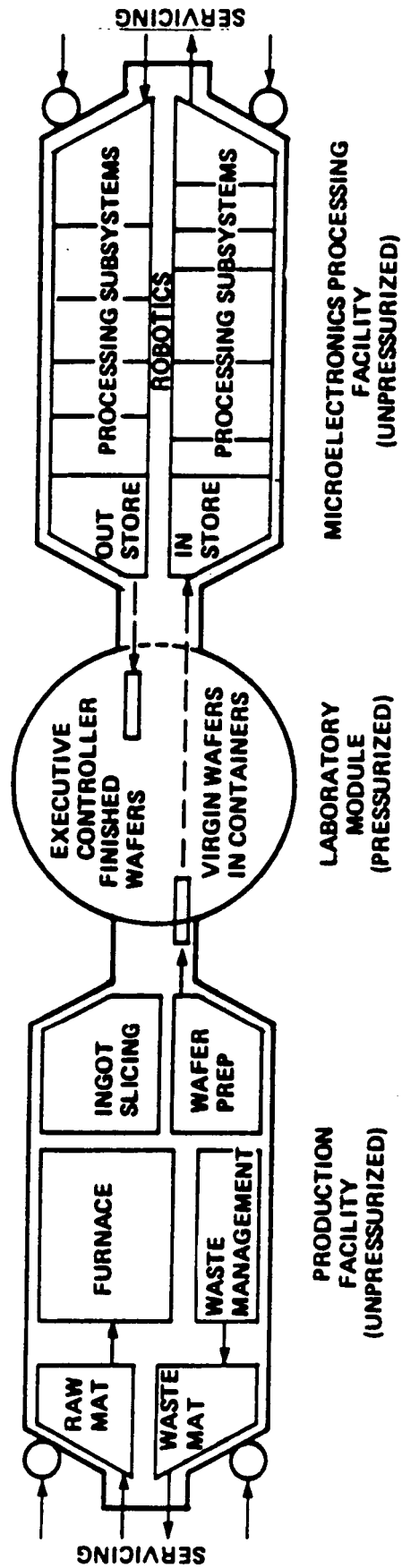
APPLICATION OF ROBOTICS TECHNOLOGY ON THE GROUND

# EVOLUTION OF MICRO-ELECTRONIC PROCESSING

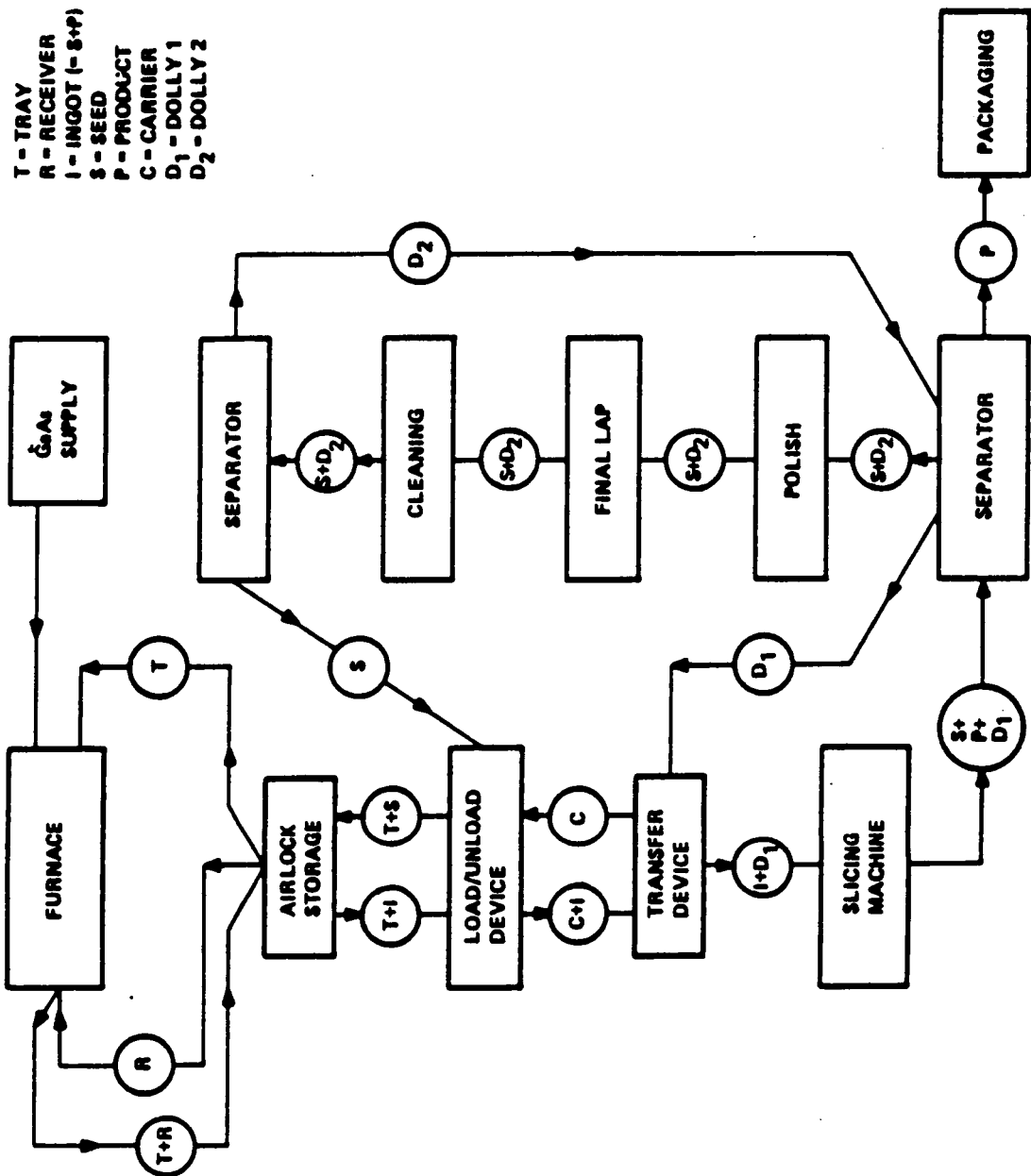
## ON THE GROUND

- FURNACE PROCESS PARAMETERS
  - Temperature ramping, process temperature control, gas flow and push-pull rate
- Management of IN-PROCESS WAFER LOTS evolved from Operator Console and Process Library (OCPL) to Wafer Inventory Control System (WICS) to Furnace Automation Control System (FACS) and now to furnace and automation management supervisory computer systems (BTU Series 2000) automated material handling.
- "HAND-OFF" WAFER HANDLING
  - EVOLUTION IN MECHANIZATION
    - MACTRONIX: Loading every slot from partially filled carriers  
Back to back loading  
Loading between solid sources
    - M GI Systems: Automatically loaded configurations
- "HAND-OFF" PROCESSING

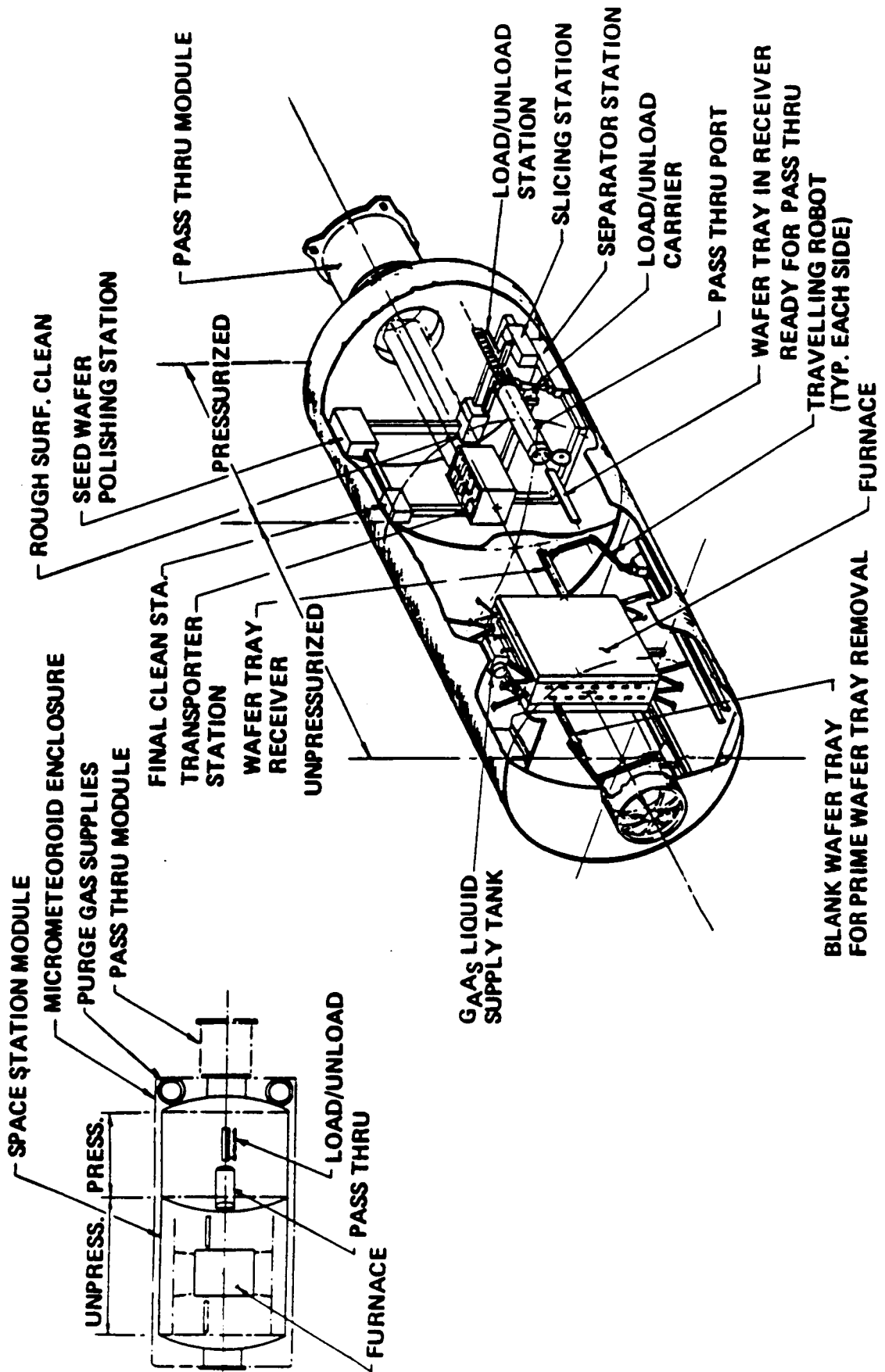
# MANUFACTURING FACILITIES DESIGN CONCEPT



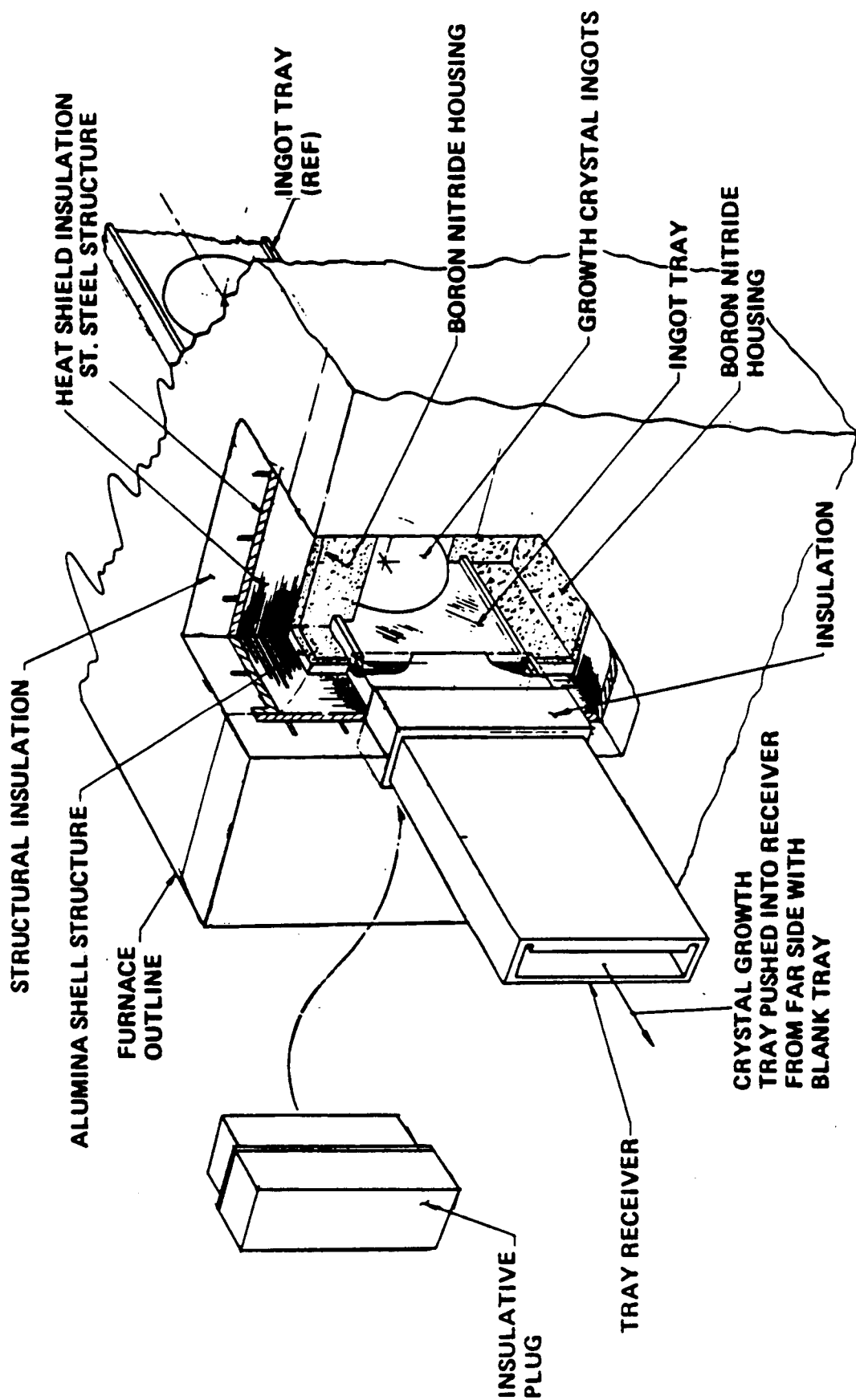
# INGOT PROCESS BLOCK DIAGRAM



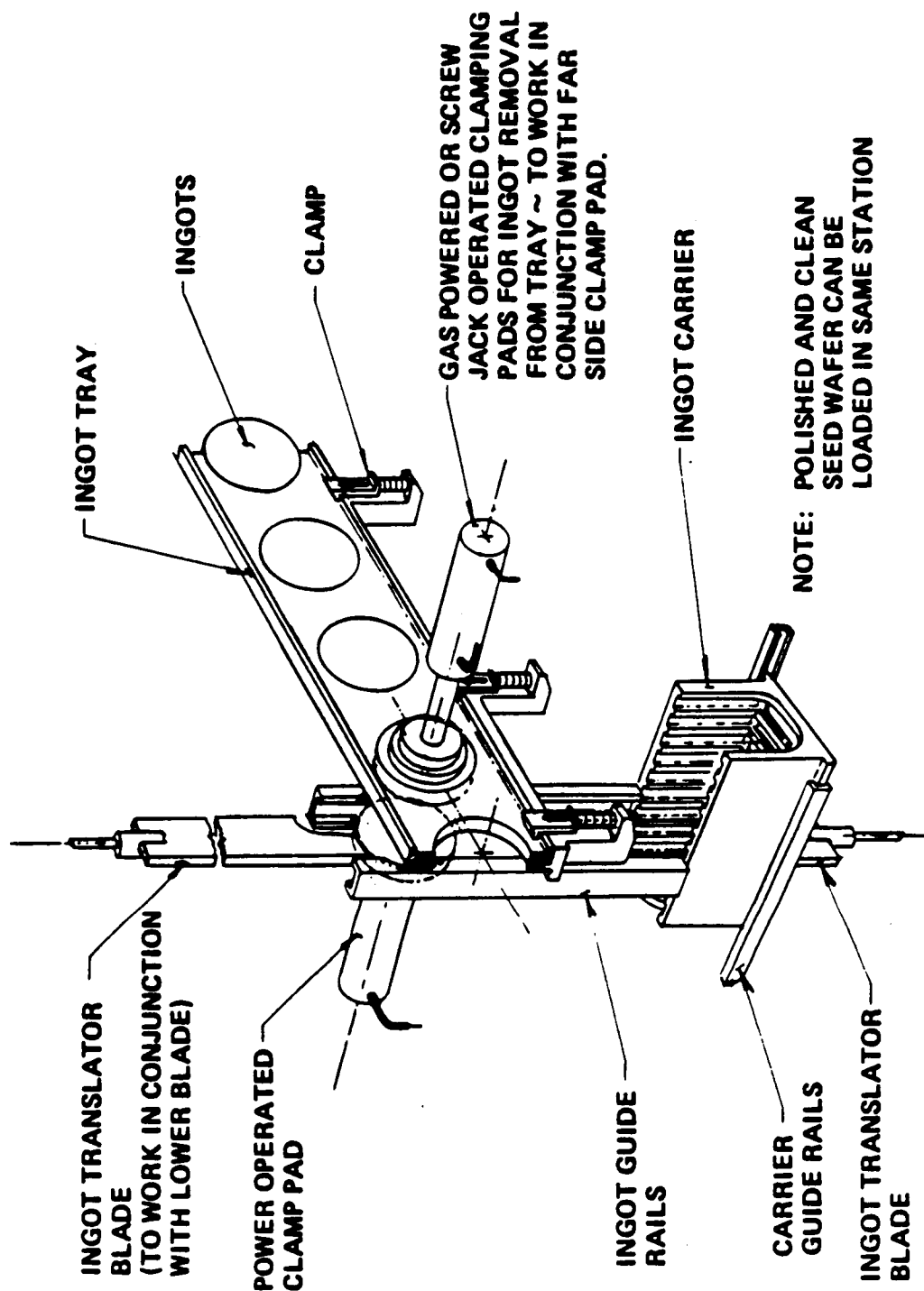
# EPITAXIAL CRYSTAL GROWTH SPACE MODULE



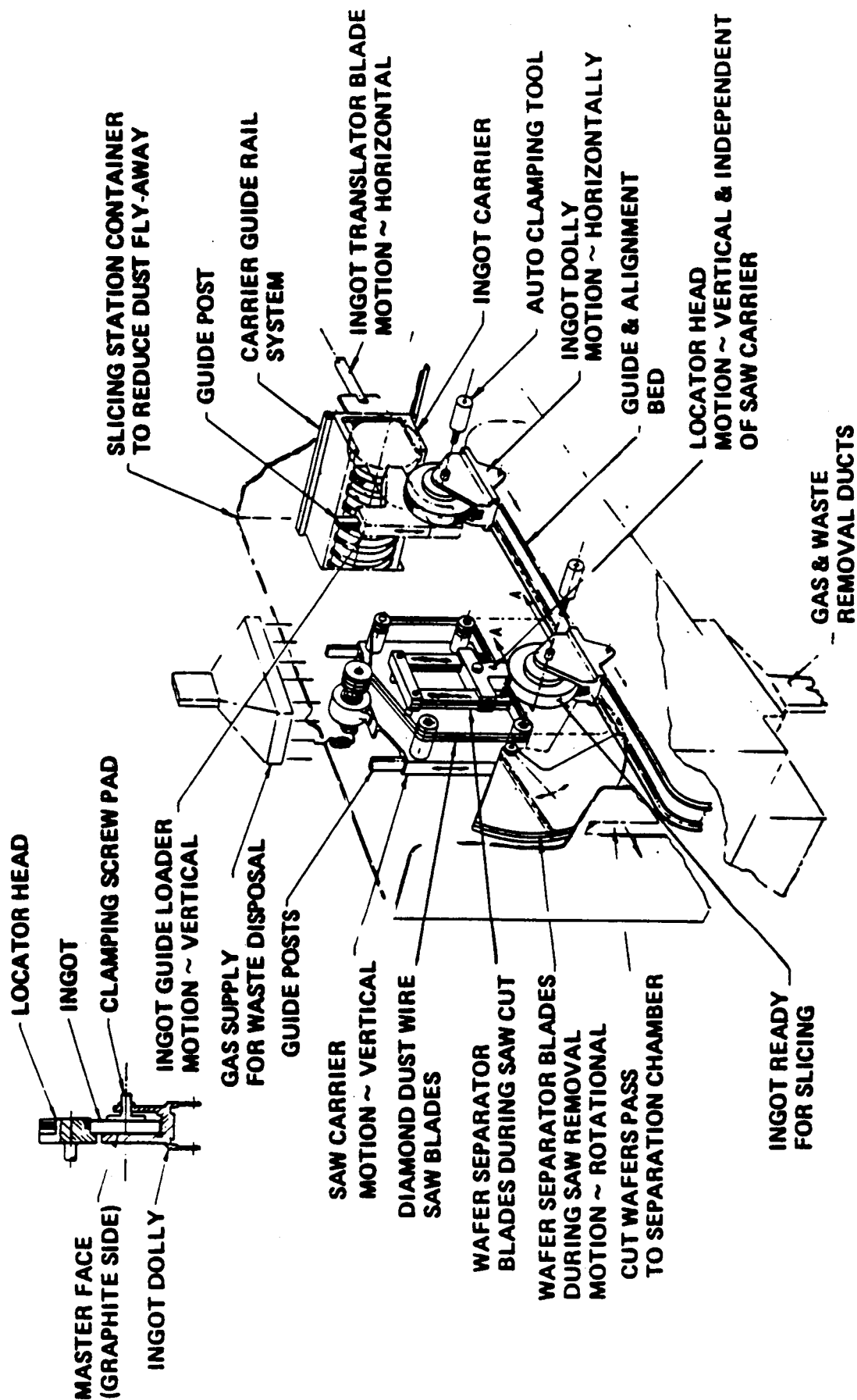
# AUTOMATED RECEIVER TRAY MATING WITH CRYSTAL GROWTH FURNACE



# AUTOMATED INGOT UNLOAD FROM TRAY

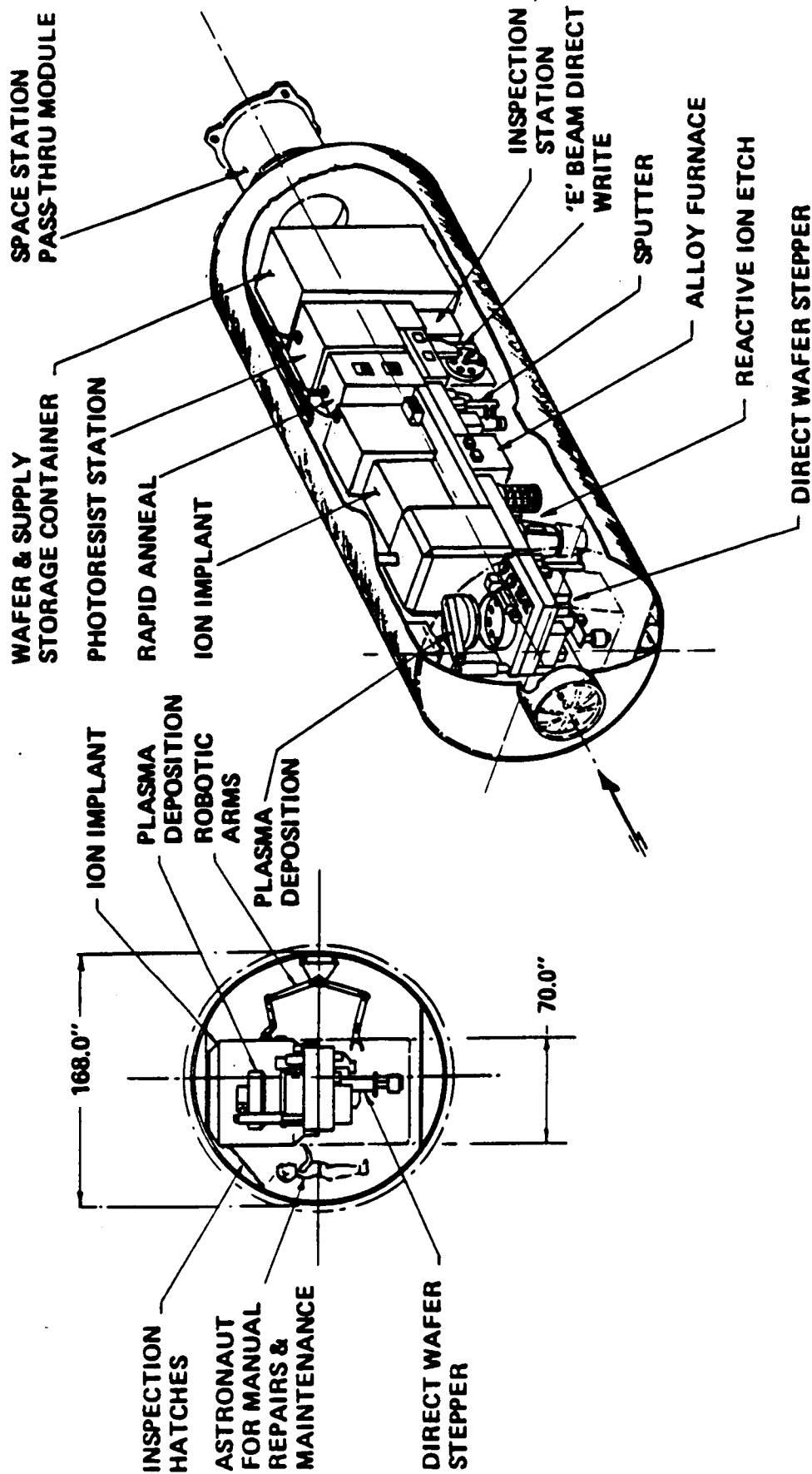


# **AUTOMATED RAW INGOT SLICING STATION**





# FULLY AUTOMATED WAFER PROCESSING FACILITY



## FUNDAMENTAL FUNCTIONS PROVIDED BY ROBOTS

- DOCK / RELEASE AT FIXTURE
- GRASP OBJECT
- MOVE OBJECT
- MOVE SELF
- PASSIVELY OBSERVE ENVIRONMENT
- MEASURE INTERACTION WITH ENVIRONMENT

## **ROBOTIC SERVICES USEABLE IN SPACE MICROELECTRONIC LABS**

- SERVICES ARE MERELY USER DEFINED AGGREGATES OF  
FUNDAMENTAL FUNCTIONS
- CLEANING AND MAINTENANCE OF LABORATORY EQUIPMENT
- FLOW OF SAMPLES WITHIN PROCESSING STATIONS
- SAMPLE TRANSPORT BETWEEN PROCESSING STATIONS
- SAMPLE INSPECTION AND RUDIMENTARY DECISION MAKING
- HANDLING AND OPERATIONS WITH TOXIC PROCESS MATERIALS
- REPLACEMENT OF "DIRTY" HUMANS IN ENTIRE LABORATORY

## ASPECTS OF SPACE WHICH INFLUENCE ROBOTS

- MICROGRAVITY
  - CONTROL ALGORITHMS FOR PRECISE MOVEMENTS
  - OBJECT GRASPING STRATEGIES
  - MEANING OF SENSOR DATA DURING MANIPULATIONS
  - DOCKING AND ANCHORING STRATEGIES
  - DYNAMIC MODELS FOR NON-RIGID MANIPULATORS
- VACUUM
  - CONTAMINATION OF WORKPIECES BY OUTGASSING
  - LOSS OF LUBRICANTS BY OUTGASSING
- THERMAL
  - CONVECTIVE COOLING LIMITED TO MARANGONI EFFECT
  - DIRECT SOLAR ILLUMINATION OR 3 DEG K BACKGROUND

## TECHNOLOGY NEEDS

- INTEGRATED SENSING CAPABILITIES:
  - VISION, FORCE AND TACTILE SENSING
  - COMPLETELY AUTOMATED SCENE ANALYSIS ROUTINES that can decompose a scene acquired into a list of parts and state the position and orientation of each part.
  - VISUAL SENSING ORGANIZED as a coherent set of part acquisition, scene analysis, object tracking and common control routines.
  - PART ACQUISITION ROUTINE to acquire part models and integrate multiple views of a part into a unified internal representation suitable for part location.
- NEW CONTROL TECHNIQUES AND SOFTWARE FOR FORCE-GUIDED CONTROL OF ROBOTS MOVING IN CONTACT WITH OTHER BODIES
- EFFICIENT MOTION AND TASK PLANNING ALGORITHMS
  - Subroutines of higher-level operation-sequence exploration codes
- GEOMETRY PROBLEMS
  - General algorithms and analysis techniques in geometry vital to mechanization planning.

# **WAFER PROCESSING INTO MICROELECTRONICS MANUFACTURING EXECUTIVE CONTROLLER REQUIREMENTS**

## **WORK STATION INTERFACES**

- 1) SYSTEM INITIATION**
  - INITIAL STATION CONFIGURATION
  - SYNCH STATION CLOCK WITH EXECUTIVE CLOCK
  - INITIATE DATA LINKS TO EXECUTIVE CONTROLLER
  - CALIBRATE INTERNAL SENSORS
- 2) MONITOR**
  - MONITOR CRITICAL STATION PARAMETERS
  - MONITOR WASTE/CONTAMINATION LEVELS
  - MONITOR SENSOR READINGS
- 3) CONTROL**
  - MECHANICAL/ELECT DEVICES
  - STATION POWER USAGE
  - CONTROL STATION TEMPERATURE
  - CONTROL CRITICAL STATION PARAMETERS
  - RECALIBRATE STATION PARAMETERS
- 4) FAULT DETECTION & HANDLING\***
  - DETECT STATION ANOMALIES
  - ISOLATE STATION ANOMALY
  - CONFIRM ANOMALY W/SYSTEM EXECUTIVE
  - RECONFIGURE STATION AS REQUIRED
- 5) TRENDING/REPORT GENERATION**
  - CRITICAL STATION PARAMETERS TRENDING
  - STATION FAULT HISTORY
  - STATION LEVEL STATUS
  - STATION QUALITY TRENDING

**\*CANDIDATE FOR AI APPLICATION**

# **WAFER PROCESSING INTO MICROELECTRONICS MANUFACTURING EXECUTIVE CONTROLLER REQUIREMENTS**

## **SYSTEM FAULT DETECTION AND HANDLING**

- 1) FAULT DETECTION\***
    - ISOLATE AMBIGUOUS ANOMALIES
    - POWER FAILURES
    - ENVIRONMENTAL CONTROL FAILURES
    - WASTE CONTROL FAILURES
    - MATERIAL CARRIER FAILURES
    - SENSOR FAILURES
  - 2) FAULT HANDLING\***
    - PRODUCTION SHUTDOWN
    - REPROGRAM FAULTY CARRIERS
    - RESCHEDULE MATERIAL ROUTES
    - REPLAN PROCESS
    - RELIEVE STATION BOTTLENECKS
    - CONFIGURE REDUNDANT COMPONENTS
    - RESYNCHRONIZE CLOCKS/TIMING
    - CONFIRM STATION LEVEL ANOMALIES
  - 3) TRENDING/REPORT GENERATION**
    - CRITICAL PARAMETER TRENDING
    - FAULT HISTORIES
    - SYSTEM LEVEL STATUS REPORTS
    - QUALITY TRENDING
- \*CANDIDATE FOR AI APPLICATION**

# **WAFER PROCESSING INTO MICROELECTRONICS MANUFACTURING EXECUTIVE CONTROLLER REQUIREMENTS**

## **SYSTEM EXECUTIVE**

### **1) PLANNING/SCHEDULING\***

- PROCESS TIMING
- MATERIALS ROUTING (STATION TO STATION)
- MATERIAL CARRIERS (ROBOT, ARMS, CONVEYORS) SCHEDULING
- MAINTENANCE, EVENTS SCHEDULING
- MATERIALS/REFURBISHMENT & MANAGEMENT
- WASTE REMOVAL MANAGEMENT
- PRODUCTION PERFORMANCE ASSESSMENT
- DATA ROUTING/SCHEDULING

### **2) SYSTEM INITIATION**

- INITIATE STATION-TO-EXECUTIVE CRITICAL DATA INTERFACE
- INITIATE STATION-TO-EXECUTIVE HIGH VOLUME DATA INTERFACE
- PROGRAM MATERIAL HANDLING DEVICES\*
- CALIBRATE SENSORS
- INITIATE EXTERNAL INTERFACES (POWER SUBSYSTEM, SPACE STATION EXEC.)
- CLOCK SYNCHRONIZATION

### **3) SYSTEM MONITORING**

- CRITICAL SYSTEM PARAMETERS (POWER, TEMP)
- WASTE/CONTAMINATION LEVELS
- ENVIRONMENTAL CONDITIONS
- RESOURCE USAGE
- PROCESS TIMING
- SENSOR READINGS
- QUALITY TESTING
- RESOURCE RESERVES

**\*CANDIDATE FOR AI APPLICATION**



**ROBOTICS TECHNOLOGY EXPERIMENT**  
**ROTEX**  
**for SPACELAB MISSION D-2**



## **ROTEX KEY REQUIREMENTS (1):**

### **TASKS TO BE PERFORMED:**

- **A&R FEASIBILITY DEMONSTRATION**
- **SAMPLE EXCHANGE UNDER MICRO – G CONDITIONS**
- **SERVICING TASKS**

### **OPERATIONAL MODES:**

- **AUTOMATIC OPERATION**
- **TELEOPERATION ON – BOARD**
- **TELEOPERATION FROM GROUND**



**ROTEX KEY REQUIREMENTS (2):**

**MANIPULATOR DESIGN:**

- 6 DOF MANIPULATOR ARM WITH
- GRIPPER - TYPE MULTI - SENSOR END - EFFECTOR

**TELEMANIPULATION:**

- 6 - AXIS SENSOR STEERING BALL
- VOICE - INPUT / OUTPUT - SYSTEM
- 3 D - COMPUTER GRAPHICS

**~~A~~ DFVLR**

**ROTEX KEY REQUIREMENTS (3):**

**PERFORMANCE REQUIREMENT:**

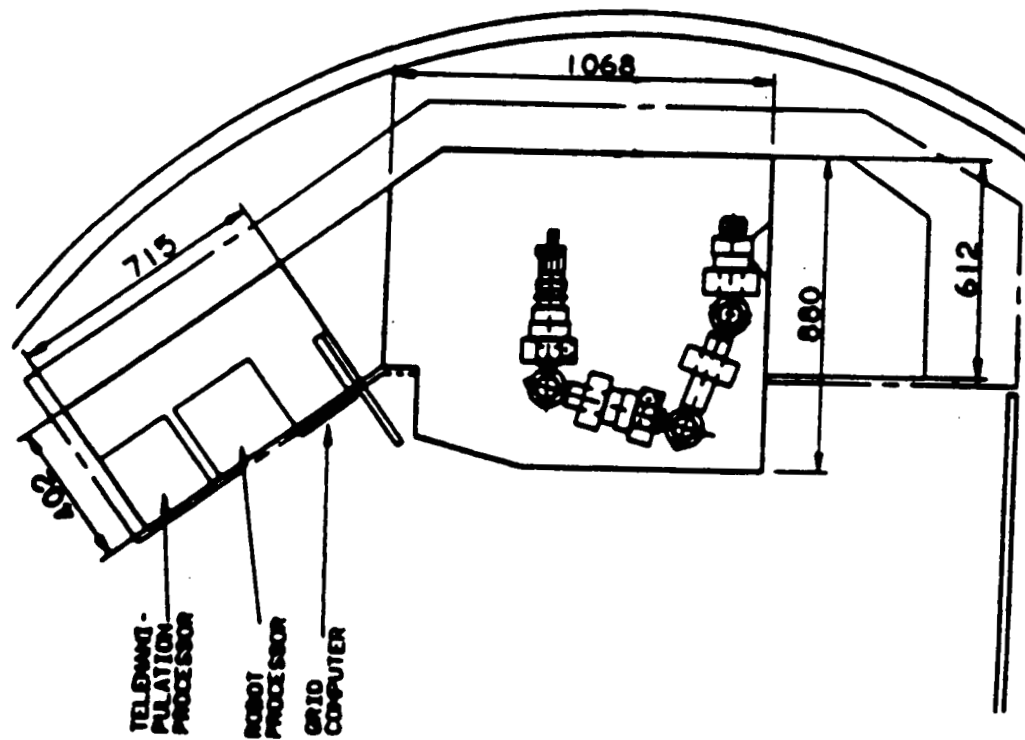
- **+/- 0.5 MM ABSOLUTE POSITION OF END - EFFECTOR**
- **+/- 0.1 MM REPEATABILITY**

**VOLUME:**

- **SPACELAB SINGLE RACK**



# **ROTEX MECHANICAL CONFIGURATION:**



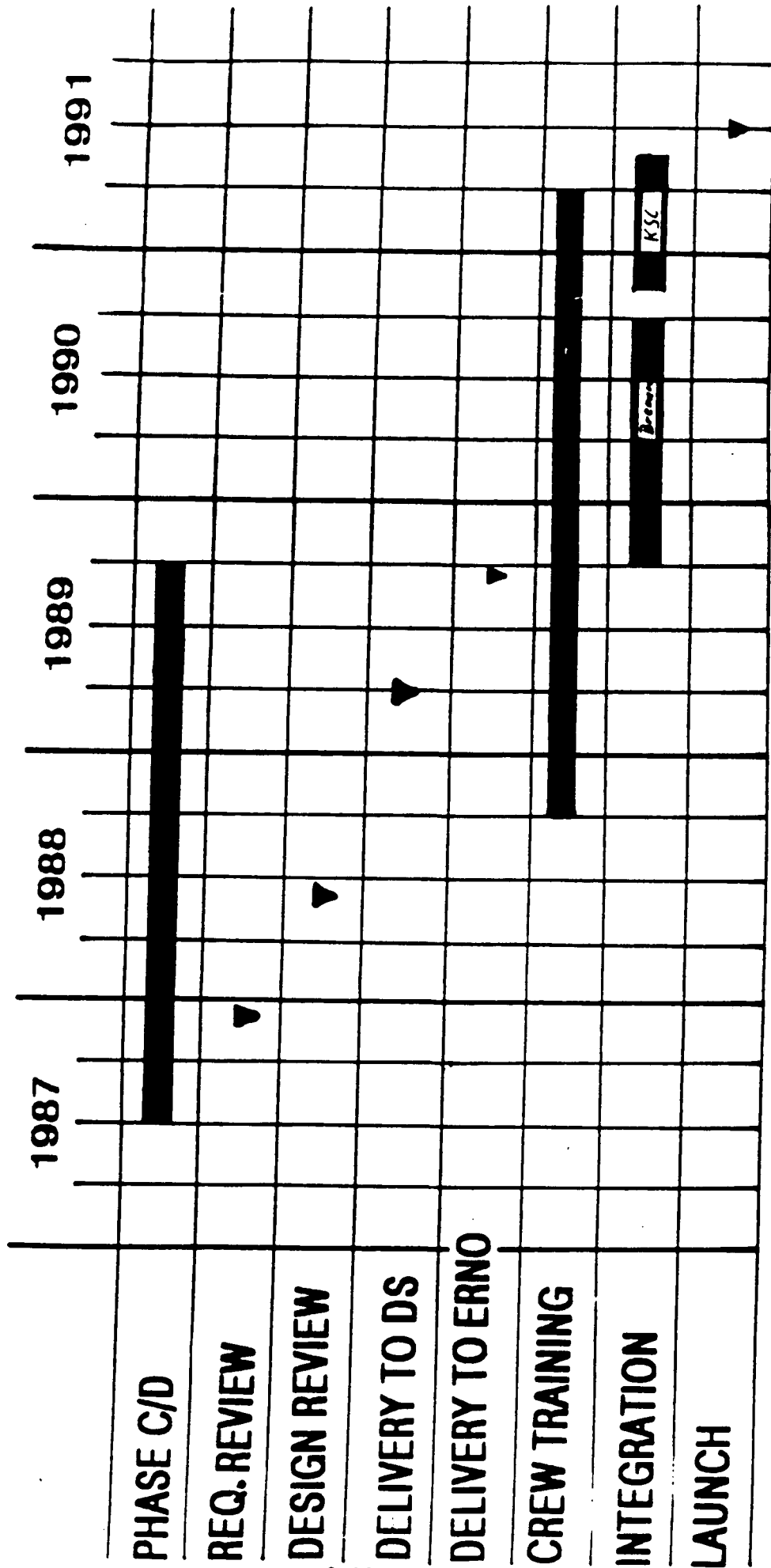
**DFVLR**

**ROTEX SENSORS:**

- 2 TV - CAMERAS, MOUNTED TO HOUSING FOR GLOBAL STEREO VIEWING
- 2 TV - CAMERAS, WITH FIBER GLASS OPTICS ON GRIPPER FOR CLOSE - UP STEREO VIEWING
- 3 - DIMENSIONAL FORCE / TORQUE SENSOR IN THE WRIST
- GRASP FORCE SENSORS IN THE FINGERS OF THE GRIPPER
- ARRAY OF 8 LASER DISTANCE SENSORS IN THE FINGERS OF THE GRIPPER

**~~A~~ DFVLR**

# ROTEX SCHEDULE:



## JPL ROTEX ADD-ON PROPOSED EXPERIMENT

- PROPOSED COMPLEMENT:
  - FORCE REFLECTING HAND CONTROLLER
  - SENSOR DATA GRAPHICS DISPLAY OF FORCE / MOMENT AND PROXIMITY SENSOR INFORMATION
- ADVANTAGES
  - PERMIT EXPANDED TELEOPERATION EXPERIMENT SEQUENCE UTILIZING BOTH ON-BOARD AND REMOTE (GROUND) PREDICTIVE CONTROL
  - FORCE-REFLECTING HAND CONTROLLER REPLACES THE DORMIER RATE COMMAND SENSOR BALL TO PERMIT COMPARISONS IN PERFORMANCE EFFICACY BETWEEN THE TWO CONTROLLERS



## **IMPLICATIONS FOR AUTOMATION - PRELIMINARY CONCLUSIONS**

- **ROBOTICS**
  - **MATERIAL HANDLING STRAIGHTFORWARD (SOA)**
  - **REPAIR/MAINTENANCE FUNCTION NOT IDENTIFIED AS YET**
- **PACKAGING OF EQUIPMENT**
  - **VOLUME REDUCTION EXTENT NOT COMPLETE**
  - **UNIFIED CONSOLE DESIREABLE**
- **EXECUTIVE CONTROLLER**
  - **EXTENSIVE USE OF AI PROBABLE**
  - **SCHEDULING, QA, AND FAULT WORK-AROUND KEY ITEMS**



AEROSPACE TECHNOLOGY DIRECTORATE

**STRUCTURES DIVISION**  
**Structural Dynamics Branch**

**NASA**

Lewis Research Center

ROBOTICS FOR COMMERCIAL MICROELECTRONICS  
PROCESSES IN SPACE WORKSHOP

**MICROGRAVITY ROBOTICS**

Douglas A. Rohn  
NASA—Lewis Research Center

## SPACE PLATFORM COMMERCIALIZATION

- PERMANENT FACILITIES IN SPACE WILL PROVIDE A NEW ENVIRONMENT FOR USERS
  - MICROGRAVITY ENVIRONMENT IS A RESOURCE
  - TECHNOLOGY DEVELOPMENT REQUIRED FOR MANAGEMENT
- ROBOTICS WILL ENHANCE/ENABLE FACILITY, CREW EXPERIMENT AND PROCESS UTILIZATION
  - HOWEVER, ANY PHYSICAL MOVEMENT REPRESENTS A POTENTIAL DISTURBANCE TO THE MICROGRAVITY ENVIRONMENT
  - $F=ma$

## TECHNICAL CHALLENGE IN MICROGRAVITY

- TWO KEY "MOTION CONTROL" ISSUES:
  - MOVEMENT OF SELECTED OBJECTS AT LESS THAN MICROGRAVITY – LEVEL ACCELERATION; and/or
  - HIGHER ACCELERATION OF FAIRLY MASSIVE OBJECTS WITHOUT IMPOSING EXCESSIVE REACTION FORCES ON PLATFORM
- NEEDS:
  - "SMOOTH,PRECISE" MOTION DEVICES (NO BACKLASH, LOW RIPPLE, EFFICIENT, etc.)
  - NEW TECHNOLOGY TO ASSURE THAT MOTIONS AND MANIPULATION INVOLVED WITH ONE PROCESS DO NOT NEGATE THE MICROGRAVITY ENVIRONMENT OF IT OR OTHERS



AEROSPACE TECHNOLOGY DIRECTORATE

STRUCTURES DIVISION  
**Structural Dynamics Branch**

NASA  
Lewis Research Center

## NASA-LeRC PROGRAMS IN ROBOTICS

- A & R PROGRAMS FOCUSED ON AI AND ORU-TYPE ISSUES
  - SPACE STATION POWER MODULE
  - SPACECRAFT 2000 PROGRAM
- SMALL PROGRAM IN MICROGRAVITY ROBOTICS  
TECHNOLOGY AS RESPONSE TO MICROGRAVITY  
MANIPULATION NEEDS
  - LeRC ACTIVITY IN MICROGRAVITY MATERIALS AND SPACE EXPERIMENTS
  - LeRC EXPERTISE IN MECHANICAL SYSTEMS AND ROLLER DRIVE
  - TECHNOLOGY CRITICAL TO SOLUTION OF PROBLEMS

LeRC PROGRAM

**MICROGRAVITY ROBOTICS TECHNOLOGY**

**OBJECTIVE:**

DEVELOP MECHANICAL TECHNOLOGY TO PROVIDE  
SMOOTH MOTION, PRECISE POSITIONING,  
AND REACTION COMPENSATION FOR ROBOTIC  
MANIPULATION IN MICROGRAVITY AND SPACE  
ENVIRONMENTS

**BENEFITS:**

- ENABLE REACTIONLESS AND/OR MICROGRAVITY  
MANIPULATION IN SPACE LAB/FACILITY
- ENHANCE TELEOPERATORS AND AUTONOMOUS  
SPACE ROBOTS WITH SMOOTH MOTION  
CAPABILITY

**LeRC PROGRAM**

**MICROGRAVITY ROBOTICS TECHNOLOGY**

**APPROACH:**

- DEFINE USER NEEDS, BENEFITS AND INTEGRATION REQUIREMENTS IN SPACE STATION LAB MODULE
- DEVELOP ROLLER (TRACTION) DRIVE TECHNOLOGY FOR ROBOT JOINT DESIGNS TO EXPLOIT CHARACTERISTICS OF: ZERO BACKLASH, NEGLIGIBLE TORQUE RIPPLE, HIGH TORSIONAL STIFFNESS, NON-(LIQUID) LUBRICATED OPERATION
- APPLY STRUCTURAL DYNAMICS TECHNOLOGIES TO SYSTEM MODELING, VIBRATION ANALYSIS, FLEXIBILITY AND REACTION COMPENSATION
- DEVELOP DYNAMIC MOMENTUM REACTION COMPENSATION TECHNIQUES AND MICROGRAVITY TRAJECTORY OPTIMIZATION



AEROSPACE TECHNOLOGY DIRECTORATE

## STRUCTURES DIVISION Structural Dynamics Branch

**NASA**  
Lewis Research Center

### WORKSHOP ISSUES

- MICROGRAVITY RESOURCE
- MECHANICAL TECHNOLOGY
  - MOTORS, DRIVES, JOINTS, STRUCTURES, END EFFECTORS
  - PRECISION, FLEXIBILITY, DYNAMICS
- WITH RESPECT TO MICROGRAVITY ENVIRONMENT:
  - WHAT PROCESS REQUIREMENTS WILL DETERMINE ROBOT SPECS?
  - WHAT TECHNOLOGY GAPS EXIST IN ROBOT MECHANICAL SYSTEMS?



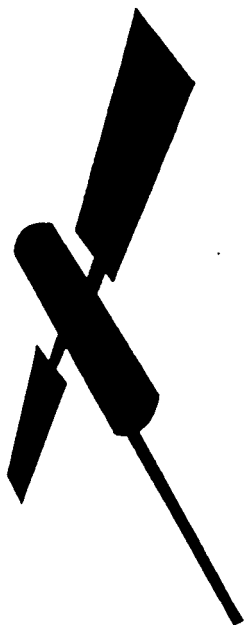


INDUSTRIAL SPACE FACILITY

C-111

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# **SPACE INDUSTRIES PARTNERSHIP**



**SPACE INDUSTRIES PARTNERSHIP**



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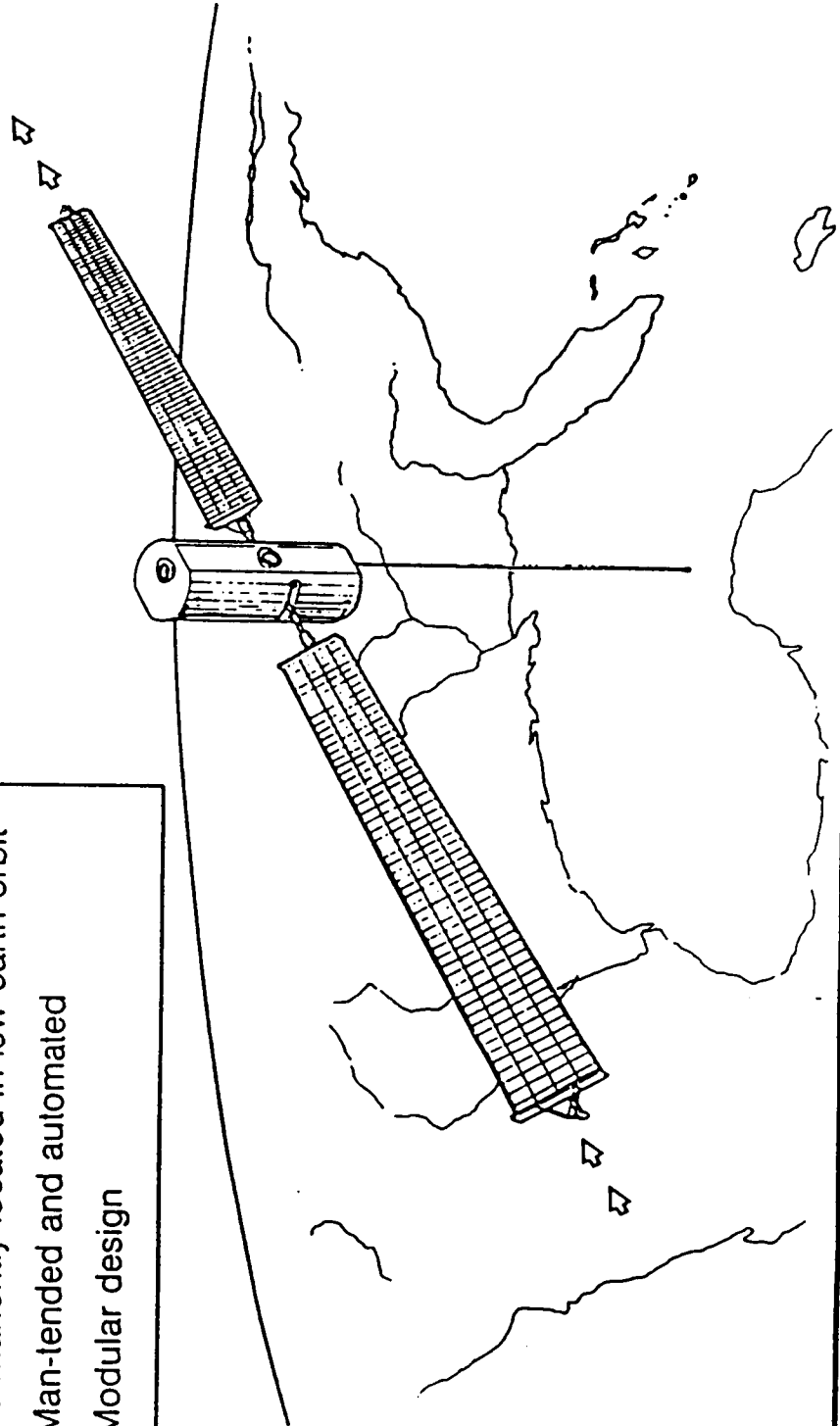
# **INDUSTRIAL SPACE FACILITY PROGRAM BRIEFING**

## **SPACE INDUSTRIES PARTNERSHIP**



## **INDUSTRIAL SPACE FACILITY**

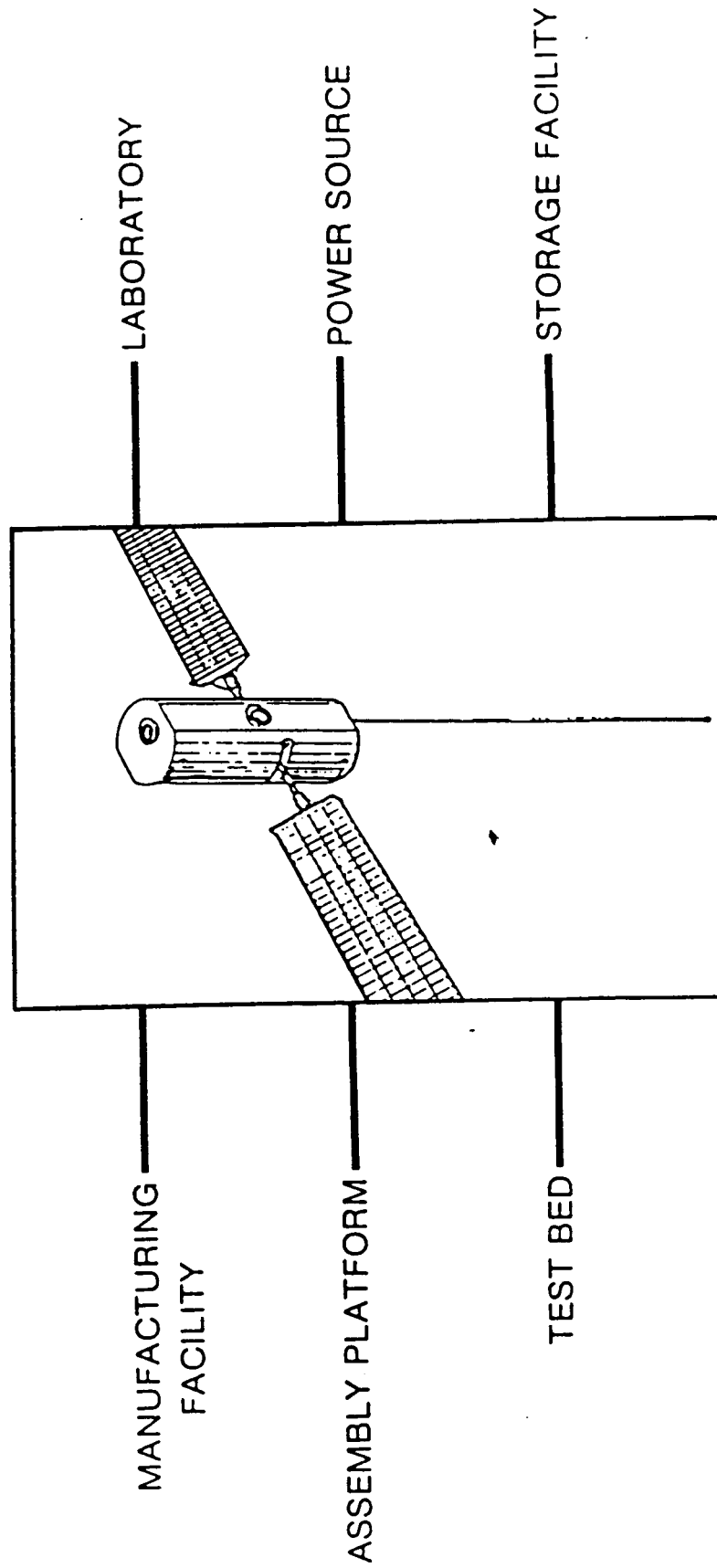
- Launched and serviced by Shuttle
- Permanently located in low earth orbit
- Man-tended and automated
- Modular design



# SPACE INDUSTRIES PARTNERSHIP



## ISF APPLICATIONS



## **SPACE INDUSTRIES PARTNERSHIP**



## **DESIGN / DEVELOPMENT APPROACH**

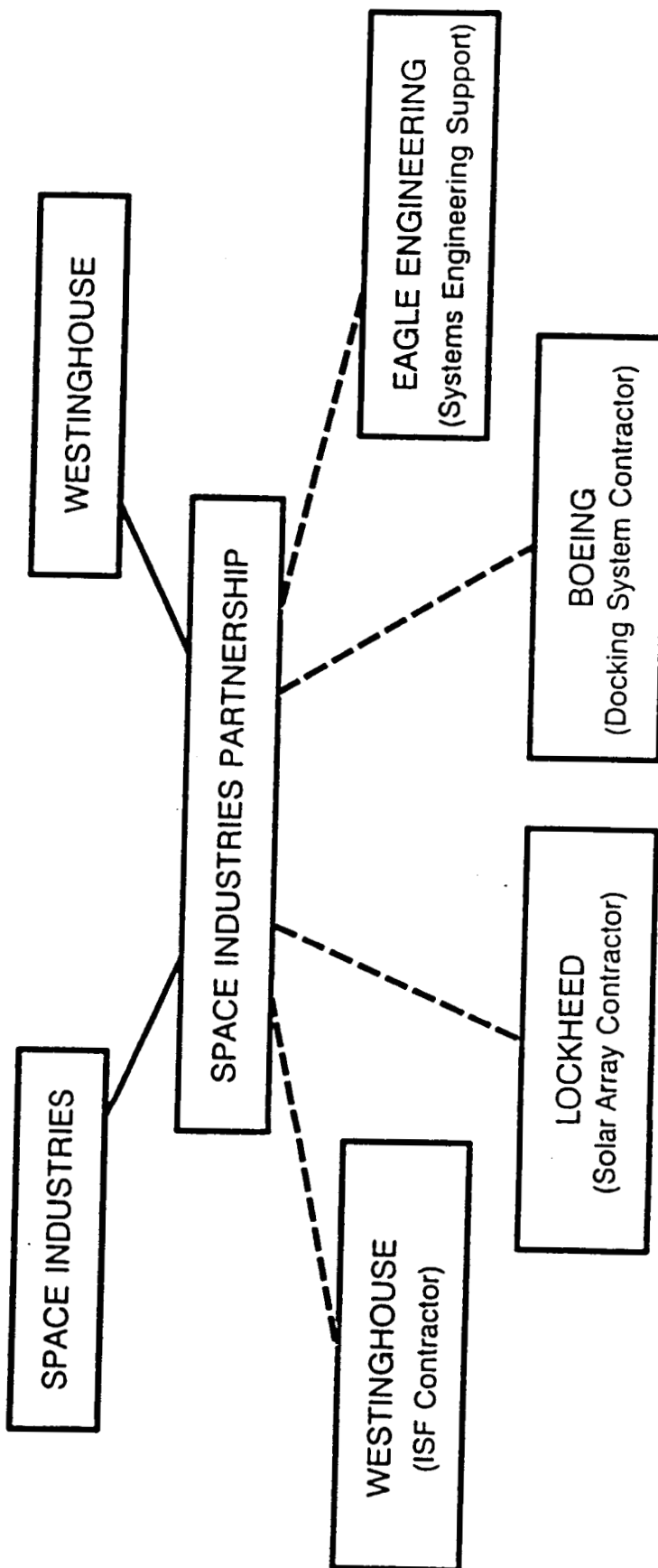
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- Capitalizes on Shuttle capabilities
- Maximizes use of proven, off-the-shelf equipment and technology
- Provides highest priority resources to users
- Achieves full operational status with one launch
- Incorporates modular design to facilitate on-orbit servicing
- Allows for growth to achieve economies of operation
- Allows for man-tended and free-flier operation
- Accommodates state-of-the-art automation and robotics
- Maintains orbit for 3 years without resupply
- Designed for 30-year orbital life

# SPACE INDUSTRIES PARTNERSHIP



## ISF PROGRAM TEAM



## **SPACE INDUSTRIES PARTNERSHIP**



## **TECHNICAL LEADERSHIP**

---

### **Maxime A. Faget**

- Director of Engineering and Development, JSC
- Responsible for development of all U.S. manned spacecraft

### **Joseph P. Allen**

- Space Shuttle astronaut
- NASA Assistant Administrator for Legislative Affairs

### **Caldwell C. Johnson**

- Chief Spacecraft Designer, JSC
- Internationally-recognized docking systems expert

### **Allen J. Louviere**

- Assistant Director of Research and Engineering, JSC
- Manager of Space Station Systems Engineering and Integration, JSC



## **SPACE INDUSTRIES PARTNERSHIP**



## **U.S. GOVERNMENT BACKING**

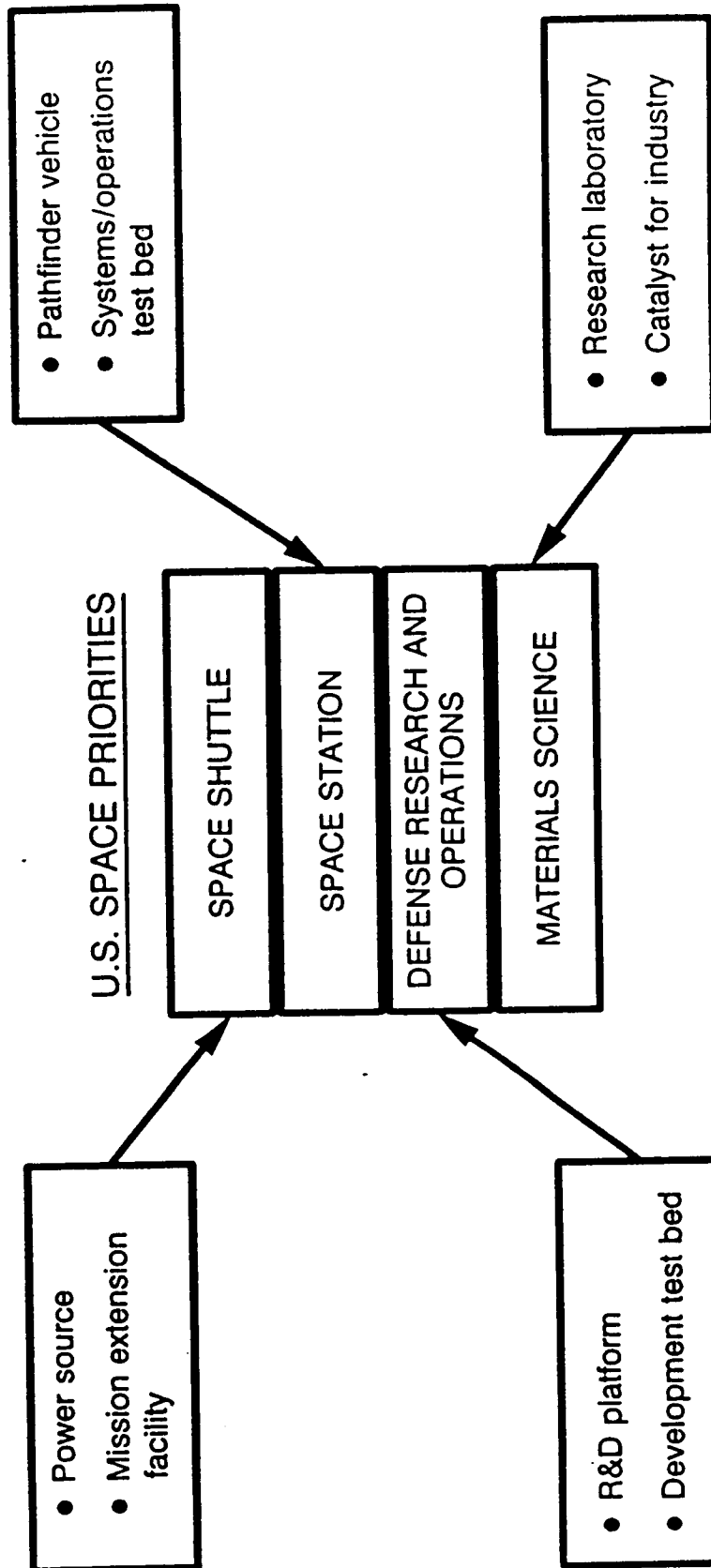
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- **Space System Development Agreement**
  - provides 3 Shuttle flights on deferred payment basis
- **Memorandum of Understanding with Space Station Program Office**
  - establishes goal of ISF/Space Station operational compatibility
- **Official Shuttle manifest**
  - reflects ISF as primary commercial payload

**SPACE INDUSTRIES PARTNERSHIP**



**SUPPORT OF  
NATIONAL SPACE PRIORITIES**

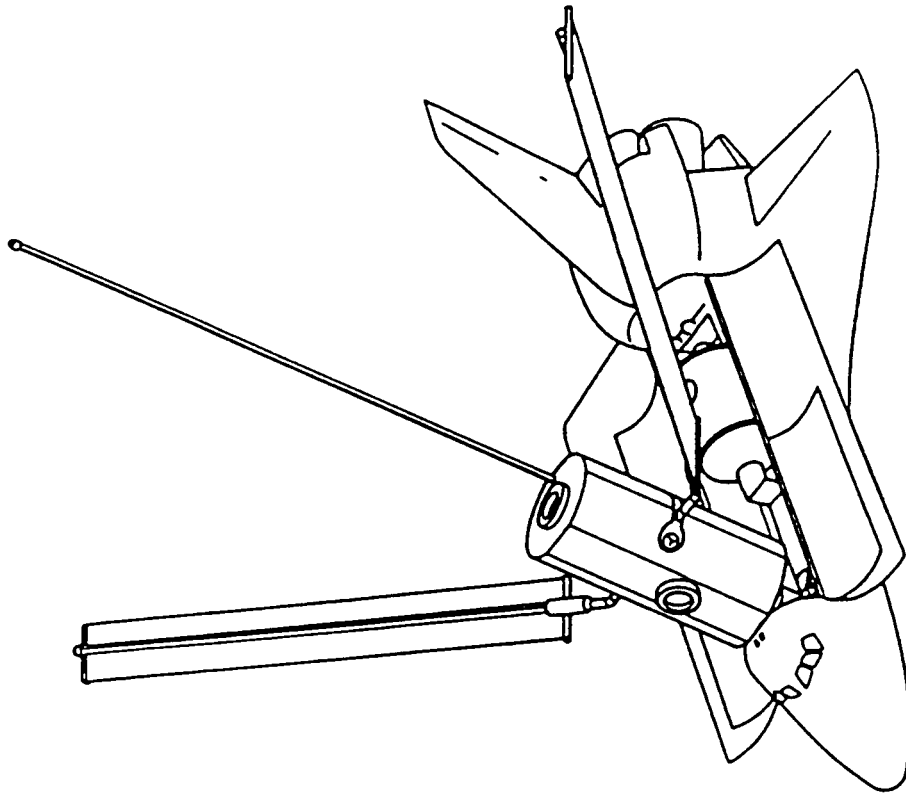


## **SPACE INDUSTRIES PARTNERSHIP**



## **SHUTTLE ENHANCEMENT**

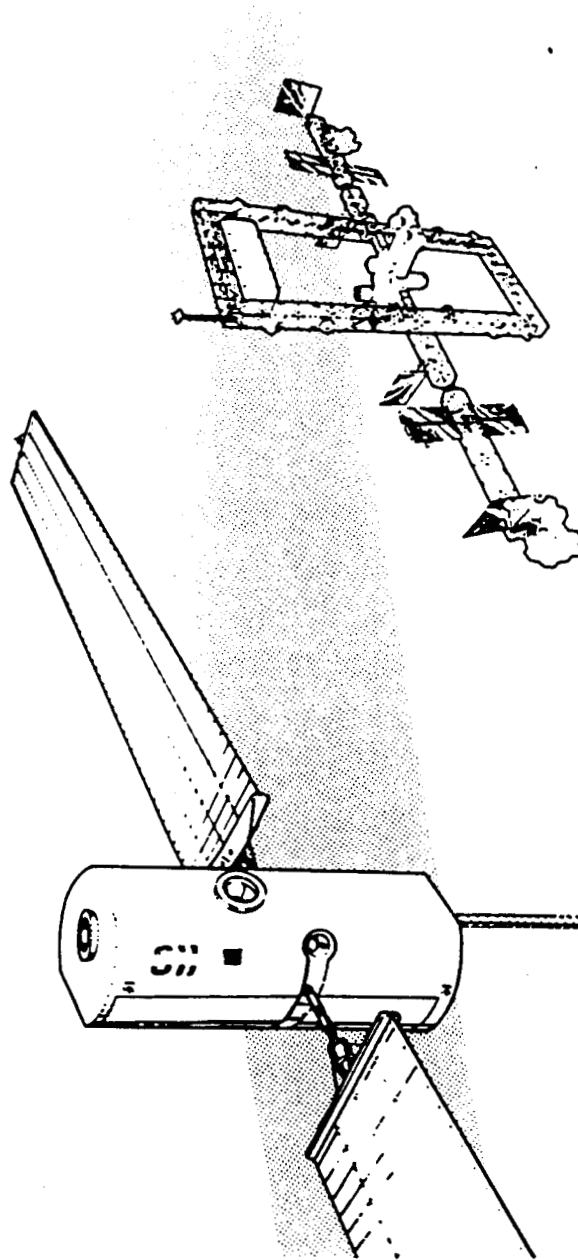
- On-orbit mission extension
- Additional power
- Shirt-sleeve work space
- Storage capacity



## **SPACE INDUSTRIES PARTNERSHIP**



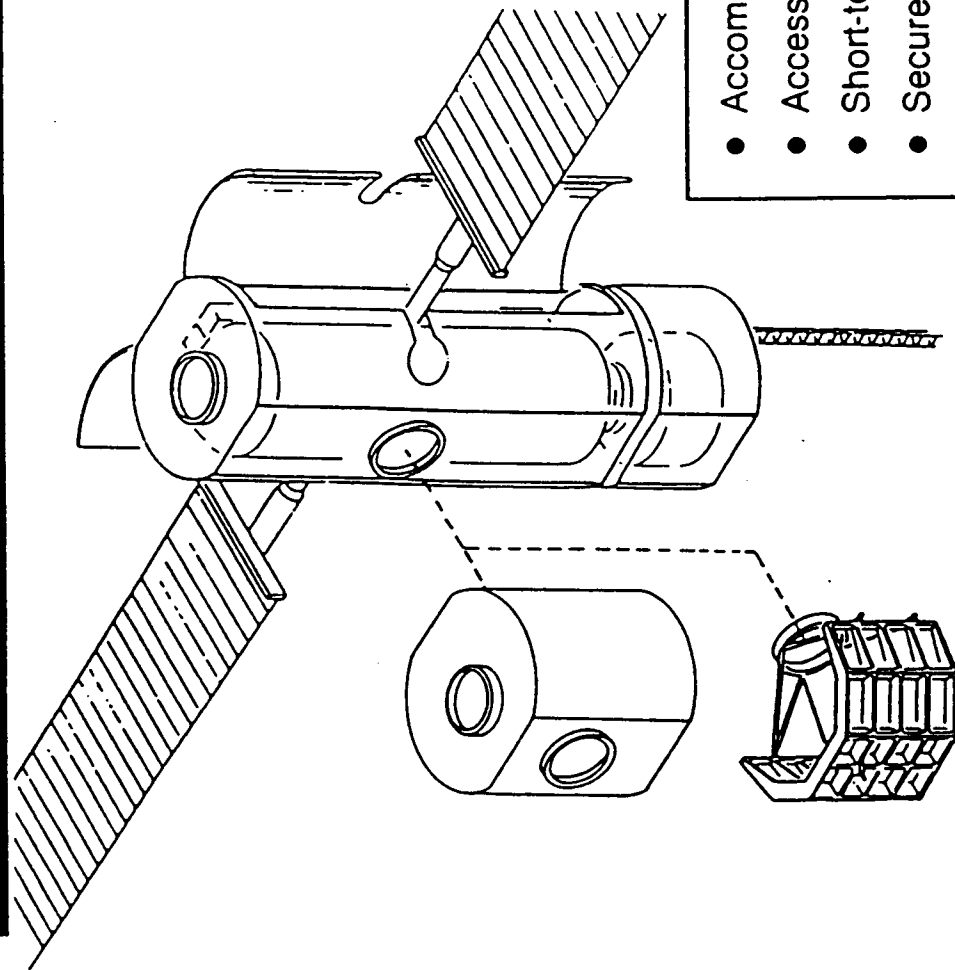
## **SPACE STATION PATHFINDER**



- Test facility for systems, user equipment, logistics and operating procedures
- Shuttle mission extender to support Space Station build-up

## **SPACE INDUSTRIES PARTNERSHIP**

## **DEFENSE RESEARCH AND OPERATIONS**

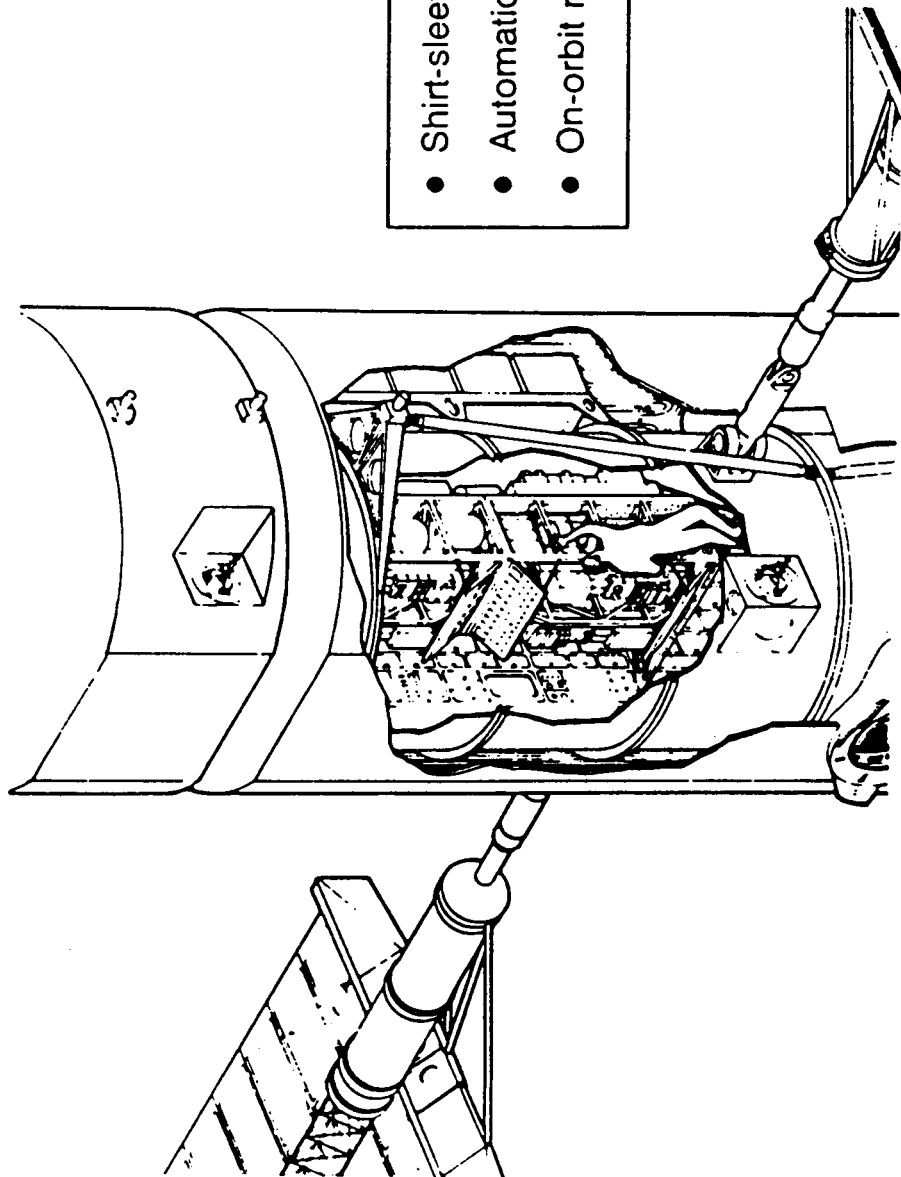


- Accommodation of special-purpose equipment
- Access to open space
- Short-term high power surges
- Secure and controlled integration and operations

**SPACE INDUSTRIES PARTNERSHIP**



## **MATERIALS SCIENCE LABORATORY**

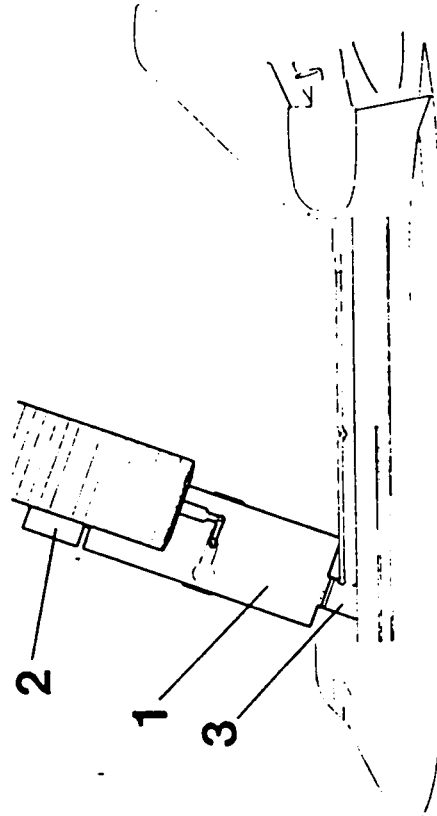


- Shirt-sleeve work environment
- Automation and robotics capability
- On-orbit reconfiguration and servicing



## **ISF SYSTEM ELEMENTS**

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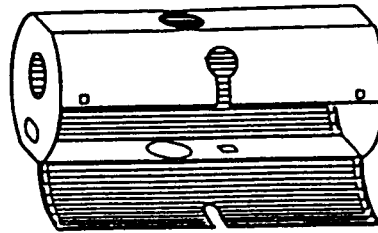
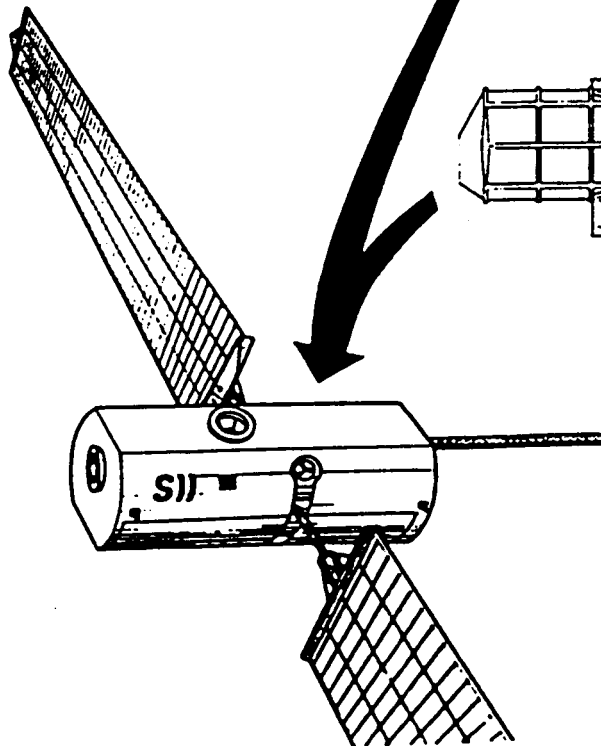
- 1. Facility Module**
  - Remains permanently in space
  - Provides basic utilities
- 2. Auxiliary Module**
  - Transports consumables, equipment and other materials
  - Provides isolated environment
- 3. Docking System**
  - Remains attached to Shuttle
  - Provides pressurized connection between Shuttle and ISF

**SPACE INDUSTRIES PARTNERSHIP**

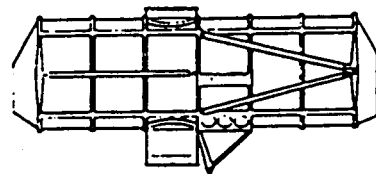


## **FACILITY MODULE**

FACILITY MODULE	
Overall Length	35.0 ft.
Outside Diameter	14.5 ft.
Pressurized Volume	2,500 cu. ft.
Power to Users	up to 10.8 kw
Radiator Area	1,000 sq. ft.
Command/Telemetry	1 kbps/10 kbps
Total Payload Weight	up to 13,900 lbs.



**METEOROID-RADIATOR  
SHELL**



**PRESSURE HULL**



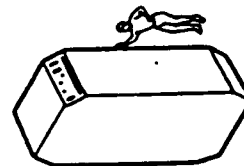
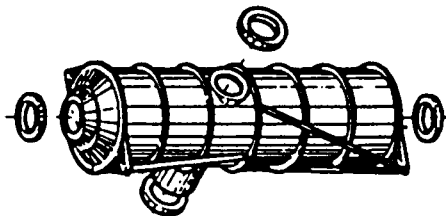
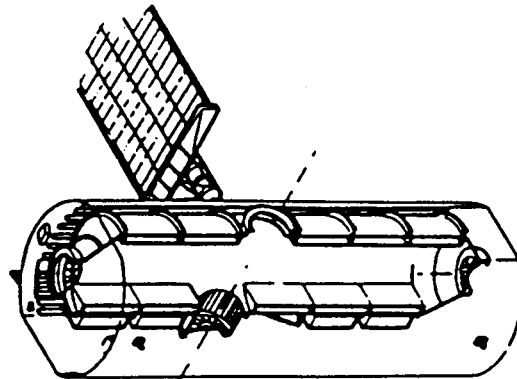
# SPACE INDUSTRIES PARTNERSHIP



## FACILITY MODULE

### PRINCIPAL SYSTEMS

Solar Arrays	2,700 sq. ft.
Power Storage	30 kwh (Batteries)
Thermal	Conductive-Convective
Propulsion	Water/Air
Data Management	Distributed Sys.
Guidance and Control	Aug. Grav. Grad.
Communication	TORSS
Navigation	GPS/GRND Update
Modular Containers	ISF Systems
Racks	User Equip.



SINGLE-USER  
CAPABILITY



MULTIPLE-USER  
CAPABILITY



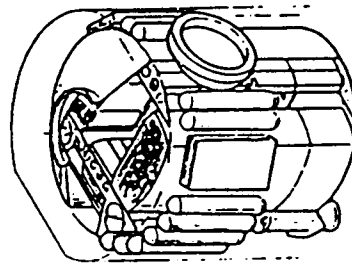
## **SPACE INDUSTRIES PARTNERSHIP**



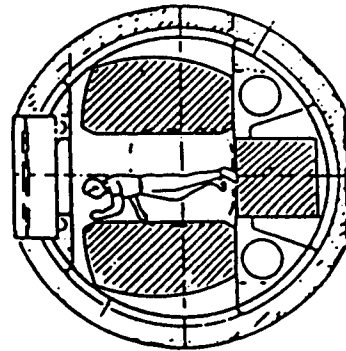
## **AUXILIARY MODULE**

### **STANDARD EQUIPMENT**

- Liquid Storage
- Gas Storage
- Up to 1800 cu. ft. Pressurized Volume



TYPICAL EXTERNAL  
CONFIGURATION

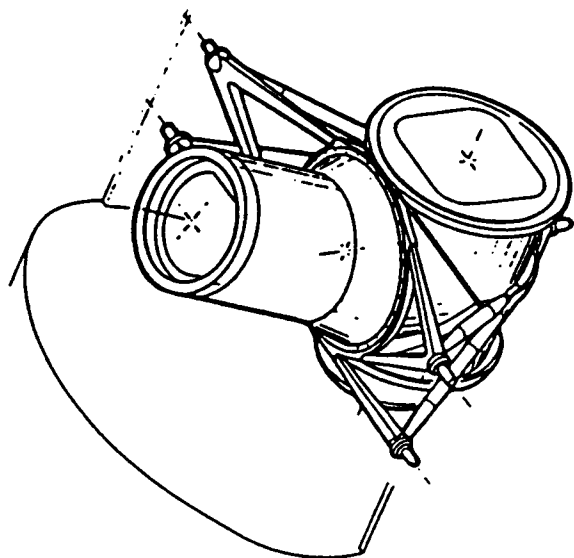
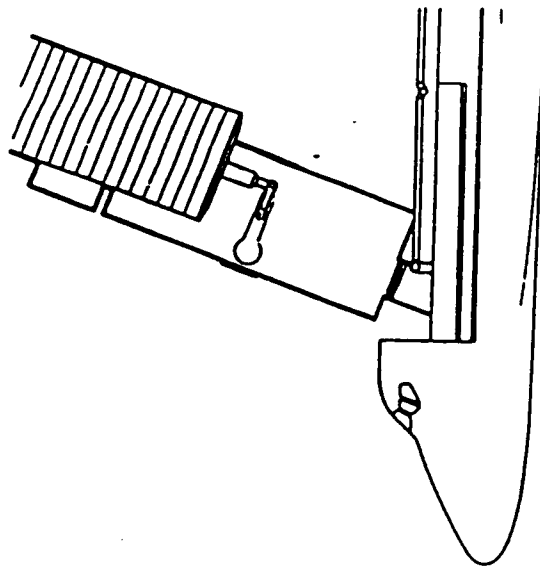


TYPICAL INTERNAL  
CONFIGURATION

**SPACE INDUSTRIES PARTNERSHIP**



## **DOCKING SYSTEM**



# SPACE INDUSTRIES PARTNERSHIP



## USER EQUIPMENT

### FACILITY MODULE

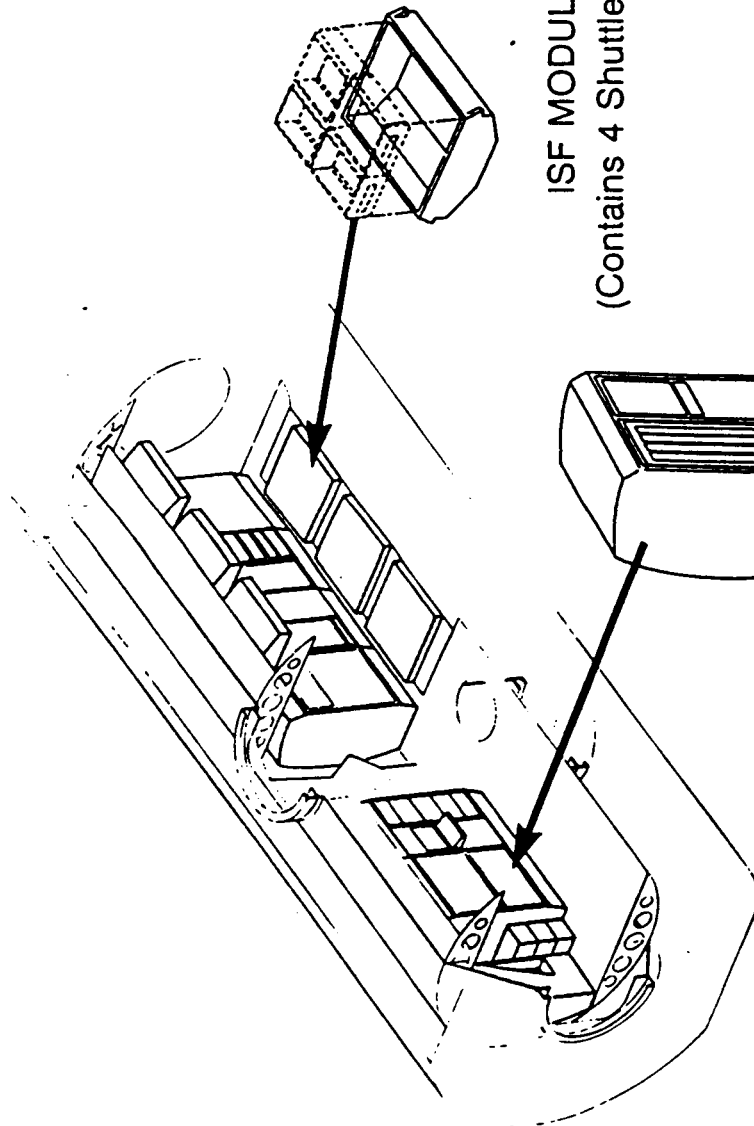
7 Racks

6 Modular Containers

### AUXILIARY MODULE

7 Racks

8 Modular Containers



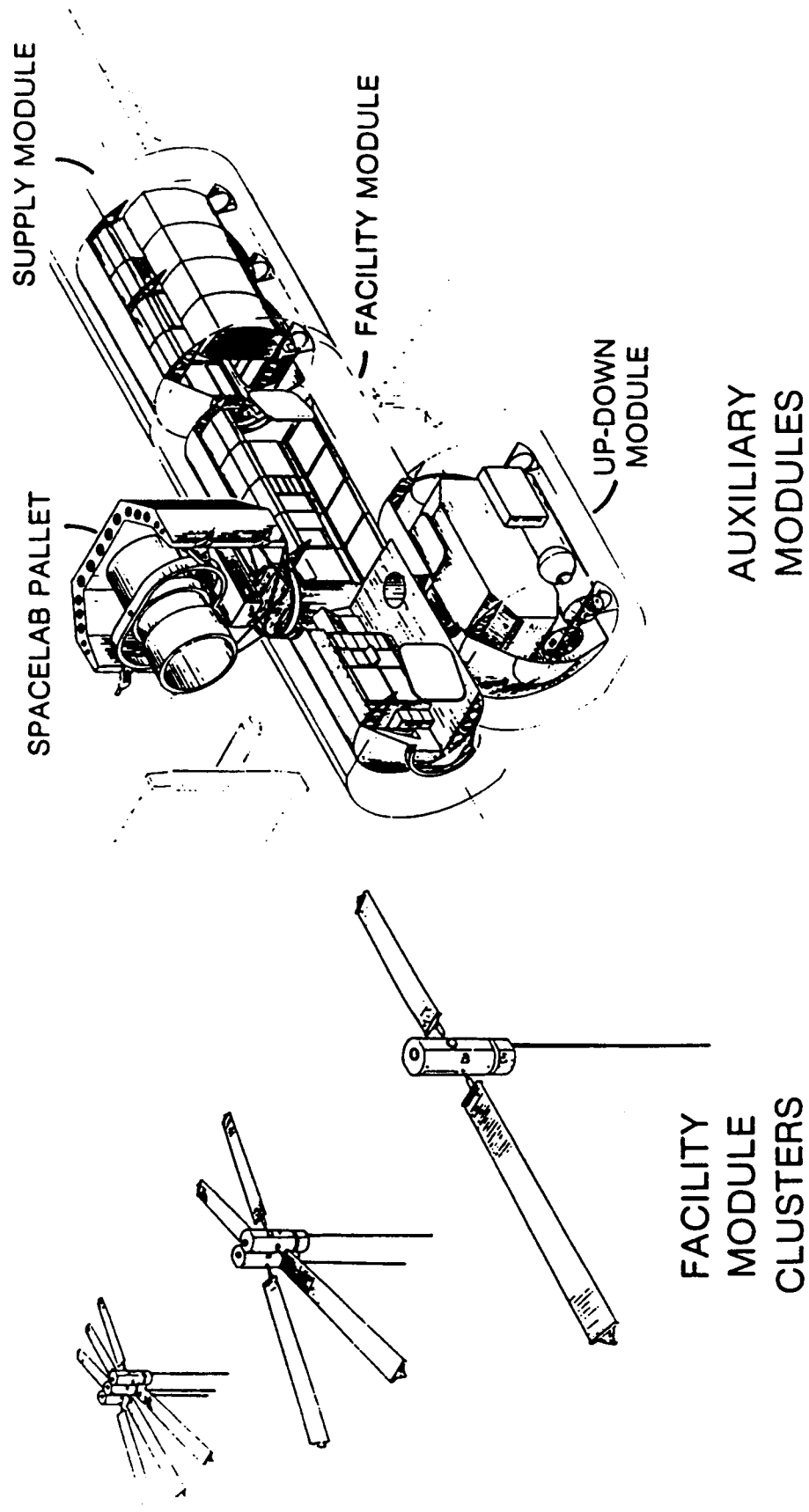
ISF MODULAR CONTAINER  
(Contains 4 Shuttle Middeck Locker Trays)

ISF RACK  
(Similar to Space Station Rack)

# SPACE INDUSTRIES PARTNERSHIP



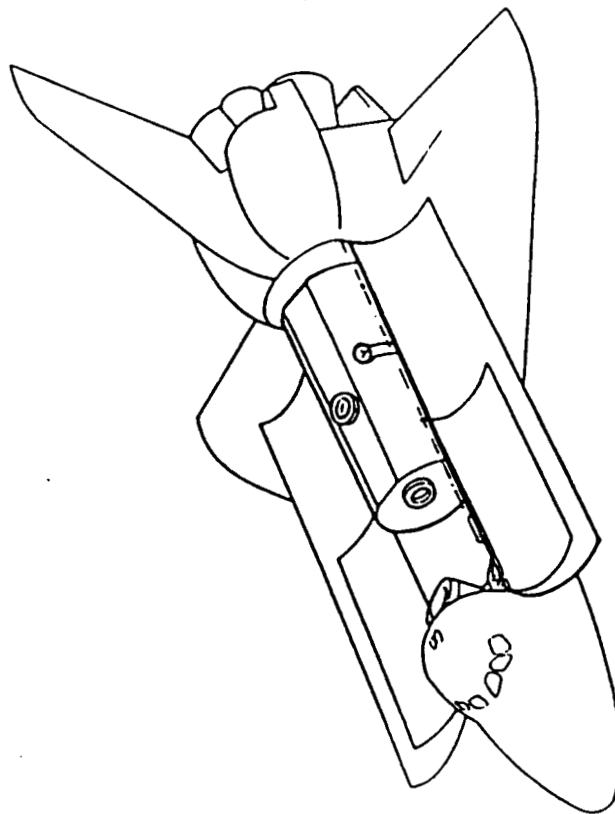
## ISF CONFIGURATION OPTIONS



# SPACE INDUSTRIES PARTNERSHIP



## INITIAL LAUNCH



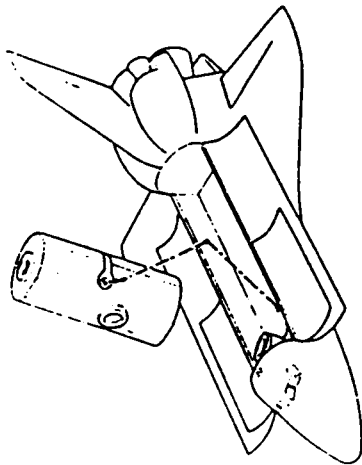
### SHUTTLE LAUNCH MANIFEST

Facility Module (and Payload)	32,697 lbs.
Docking System	2,700 lbs.
Utility Services	200 lbs.
Retention Fittings	1,733 lbs.
Payload Specialist	1,000 lbs.
Total Charged to ISF	<u>38,330 lbs.</u>

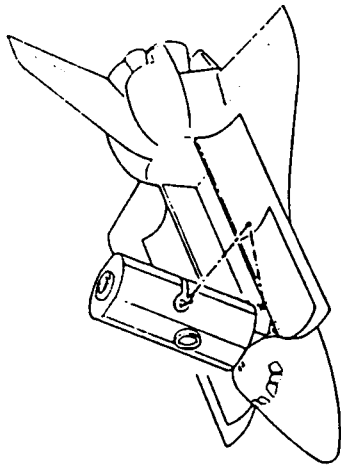
# SPACE INDUSTRIES PARTNERSHIP



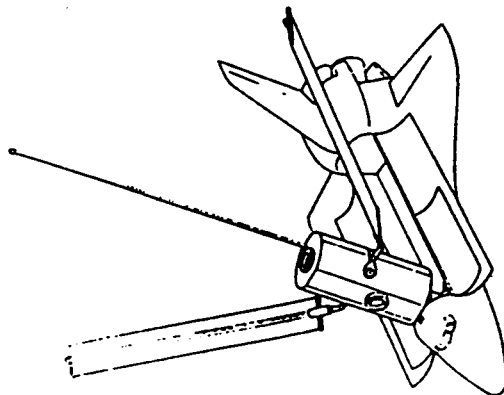
## DEPLOYMENT OF ISF



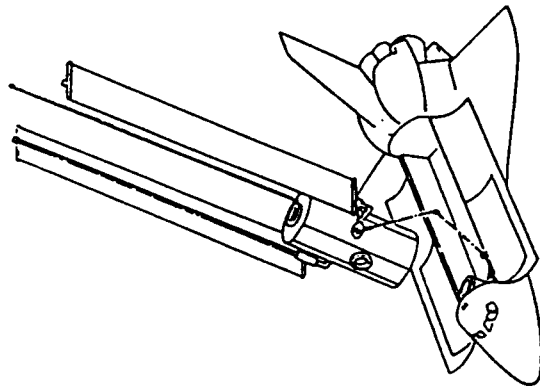
GRAPPLED  
AND MOVED  
BY RMS



FACILITY MODULE  
BERTHED TO  
DOCKING SYSTEM



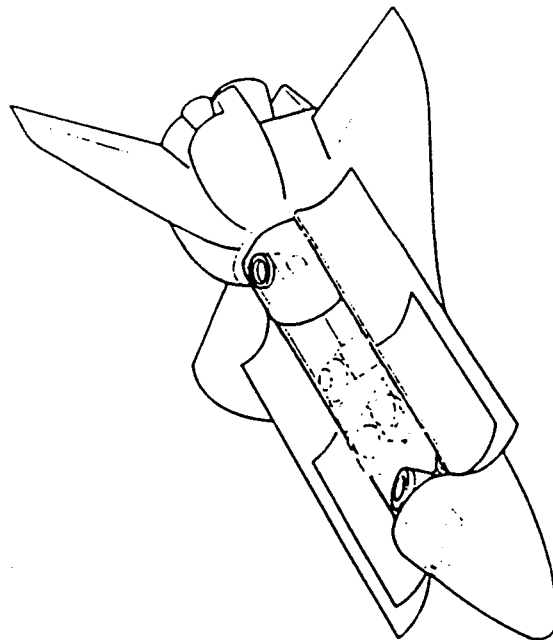
SOLAR ARRAY  
AND GRAVITY  
GRADIENT  
BOOM DEPLOYED



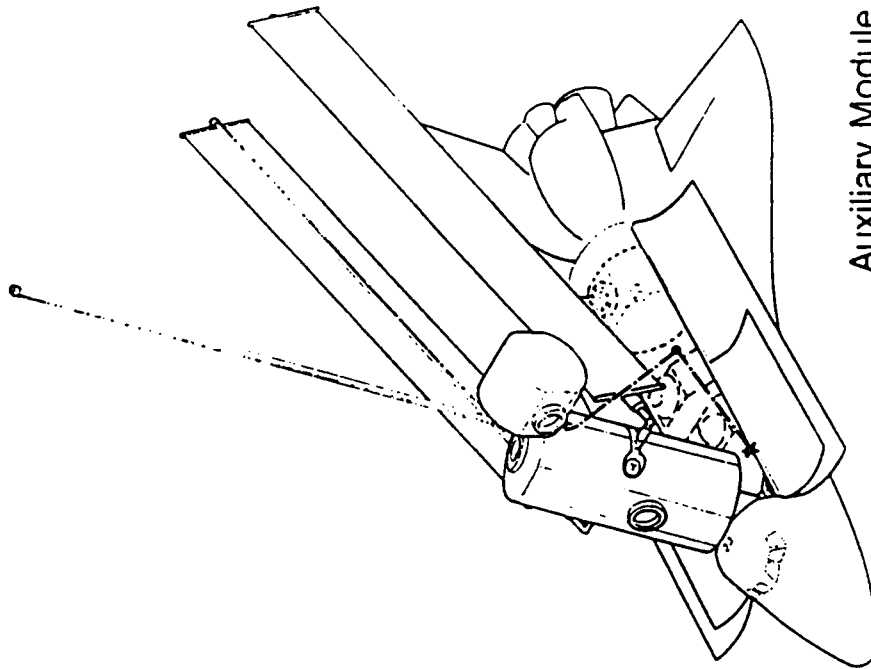
ISF  
SEPARATED  
FROM ORBITER



## **RESUPPLY OPERATION**



Auxiliary Module Carried in Shuttle



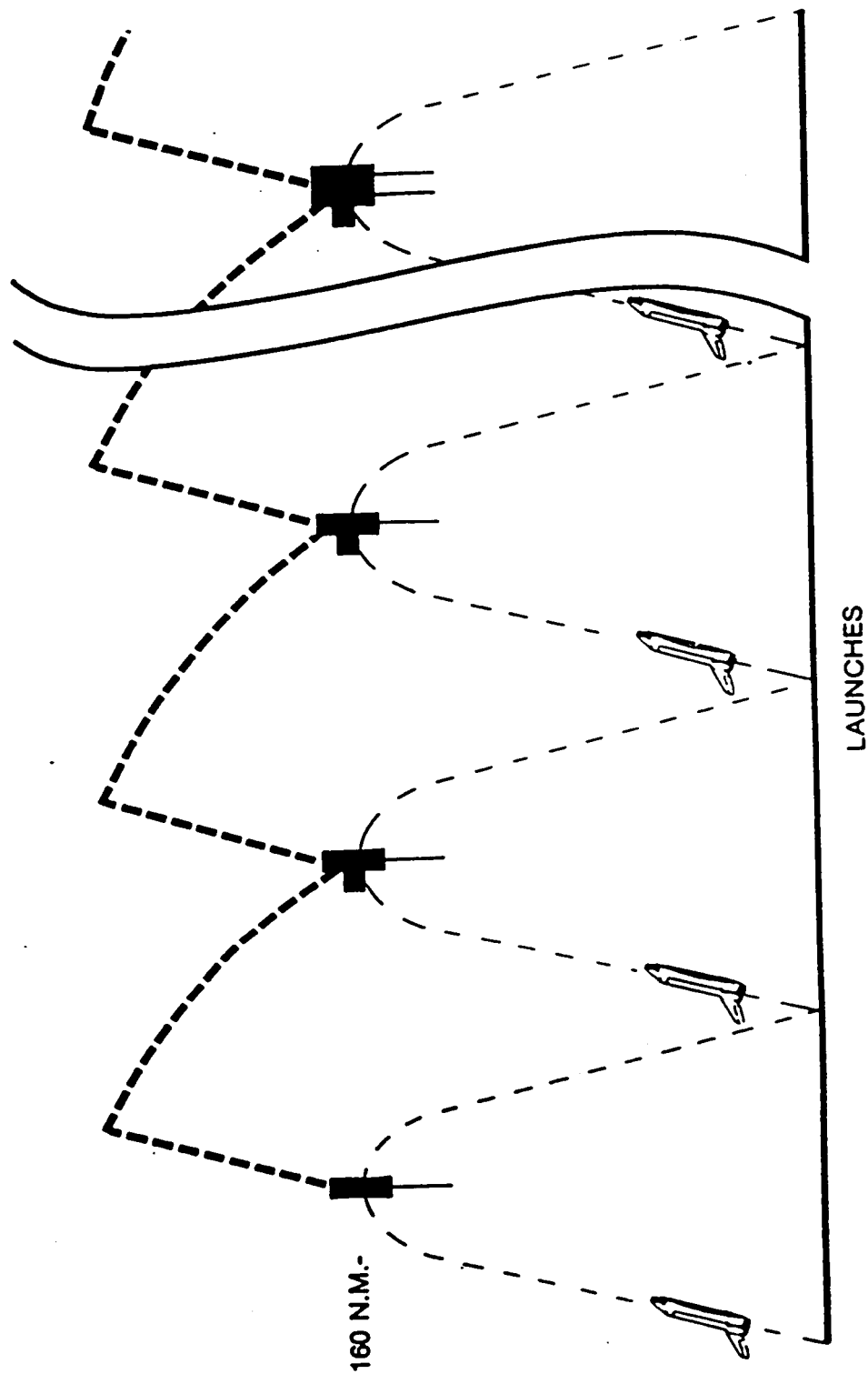
Auxiliary Module Added or  
Exchanged by RMS



**SPACE INDUSTRIES PARTNERSHIP**

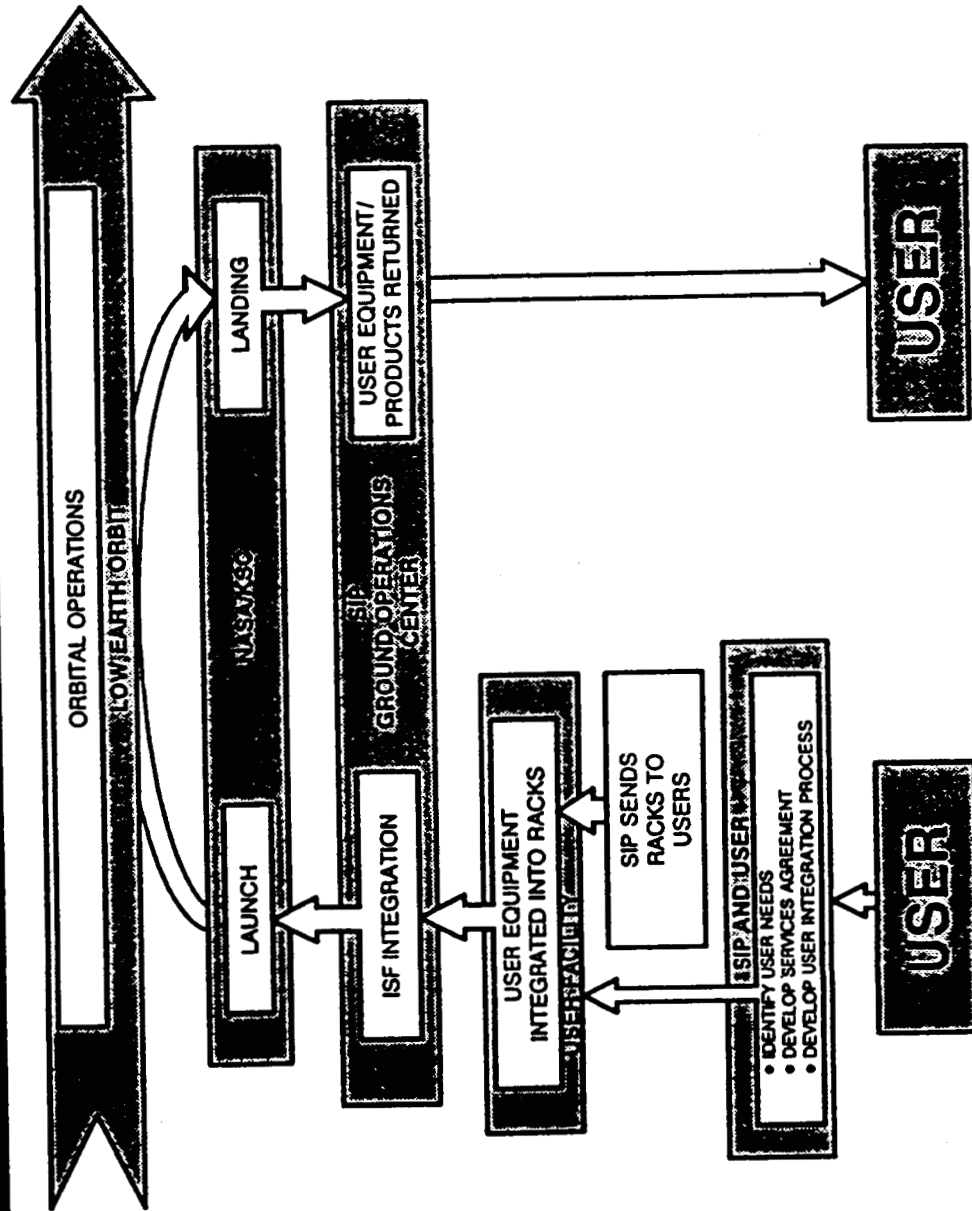


## **MISSION PROFILE**



# SPACE INDUSTRIES PARTNERSHIP

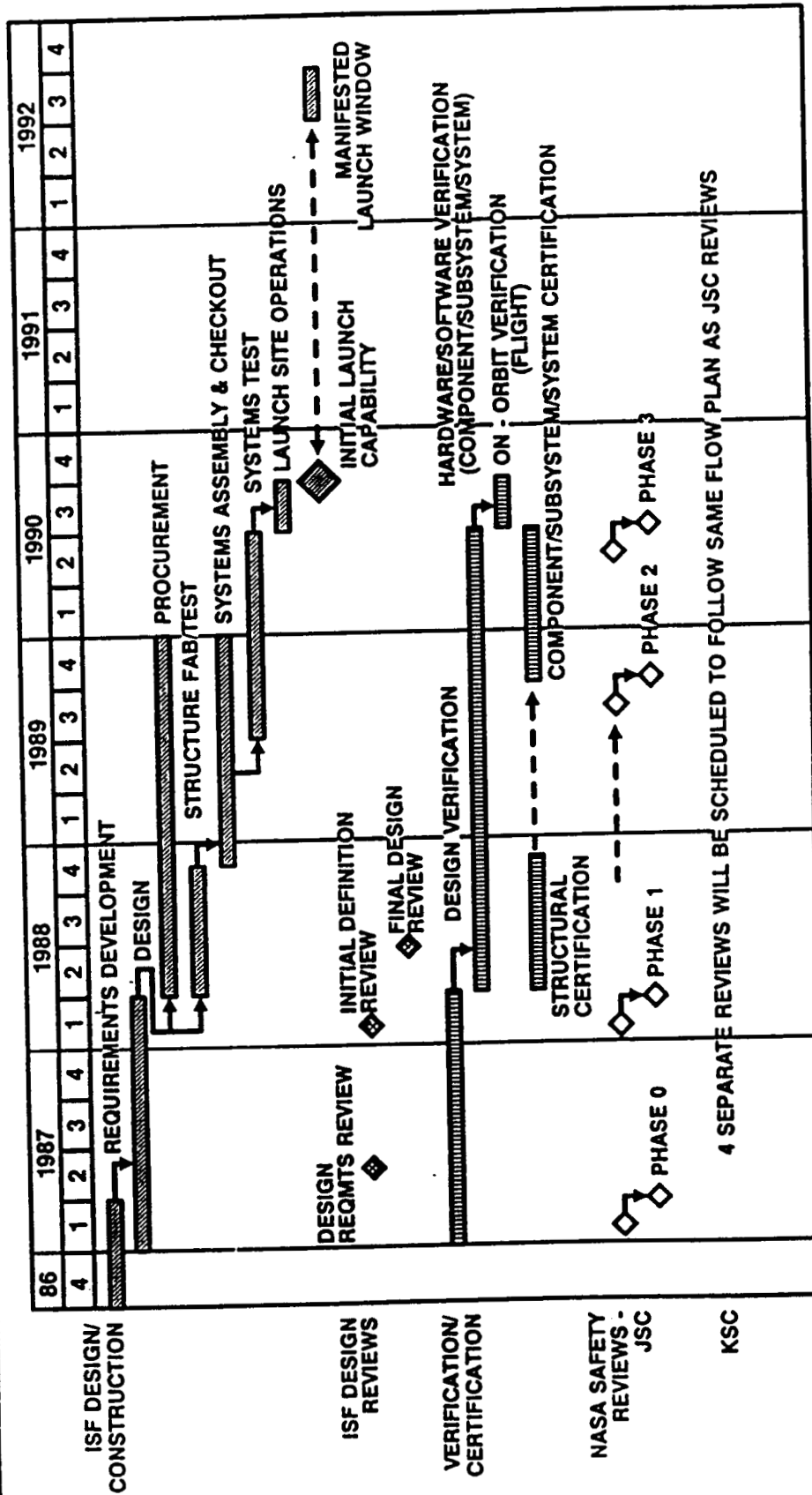
## USER INTEGRATION



# SPACE INDUSTRIES PARTNERSHIP



## ISF PROGRAM MILESTONES (INCLUDING SAFETY REVIEW CYCLE)



**CONCEPT DEVELOPMENT IDEAS**

**for the**

**ROBOTICS FOR COMMERCIAL  
MICROELECTRIC PROCESS IN  
SPACE WORKSHOP**

**SPACEHAB, Inc.**

**2-3 DEC 1987**

**SPACEHAB, Inc.  
600 Maryland Ave. S. W., Suite 201W  
Washington, D. C. 20024  
Phone (202) 488-3483**

# CONCEPT DEVELOPMENT IDEAS

FOR THE

**ROBOTICS FOR COMMERCIAL  
MICROELECTRIC PROCESS IN  
SPACE WORKSHOP**

AT

# GODDARD SPACE FLIGHT CENTER

**SPACEHAB, Inc.**  
600 Maryland Ave. S. W., Suite 201W  
Washington, D. C. 20024  
Phone (202) 488-3483

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# **SPACEHAB**

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## **Introduction**

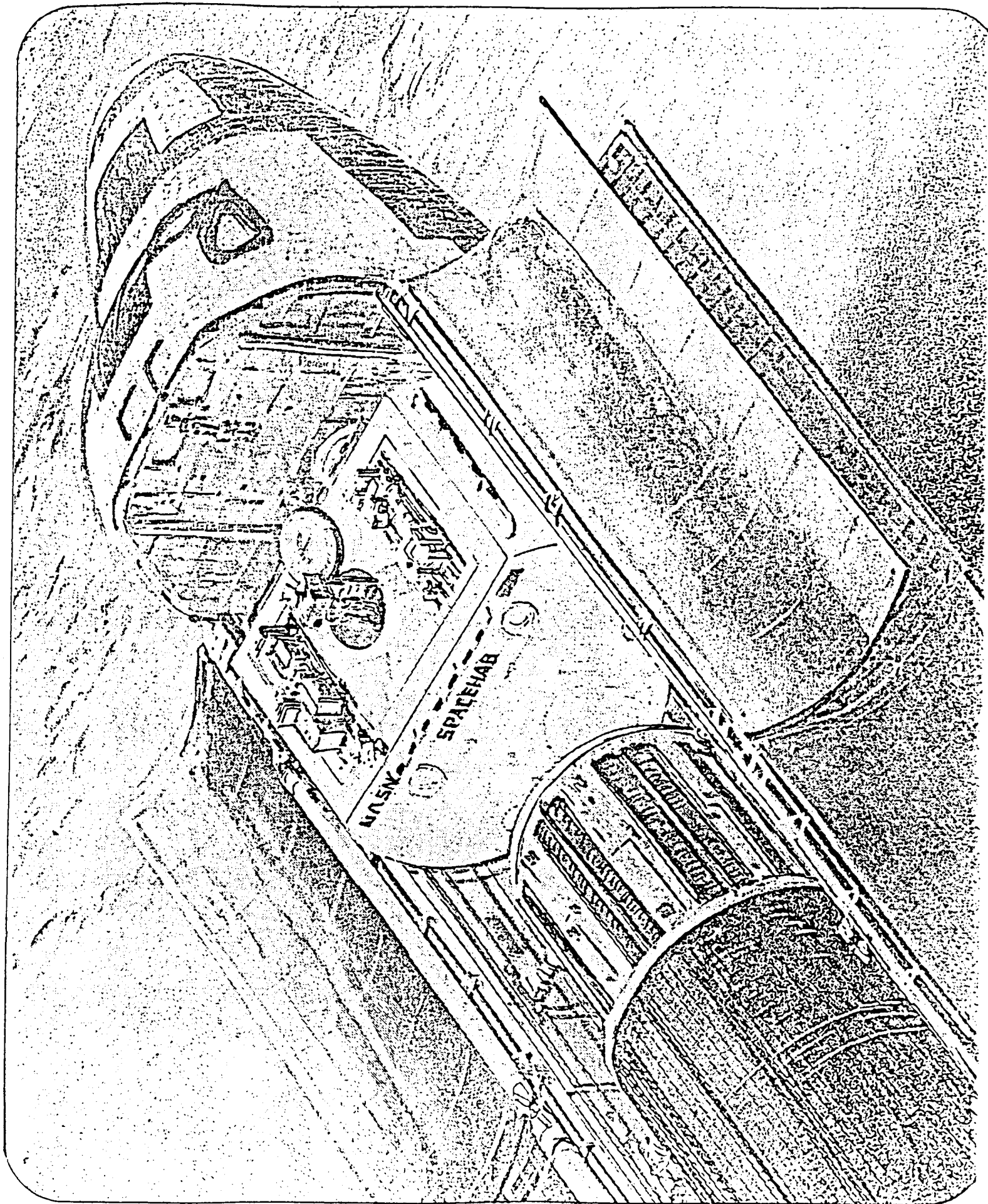
- **The Basic Module Configuration**
  - **The Module Interior Volume**
  - **Interior Robotic Concepts**
    - **- Middeck Locker Servicer**
    - **- Space Station Rack Servicer**
  - **Exterior Robotic Concepts**
  - **The Proposed Development Process**
  - **The Follow-on Possible at Space Station**
  - **Conclusions**
-

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# **SPACEHAB**

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SPACEHAB is a pressurized Space shuttle based module designed to augment the middeck volume for expanded man tended research.



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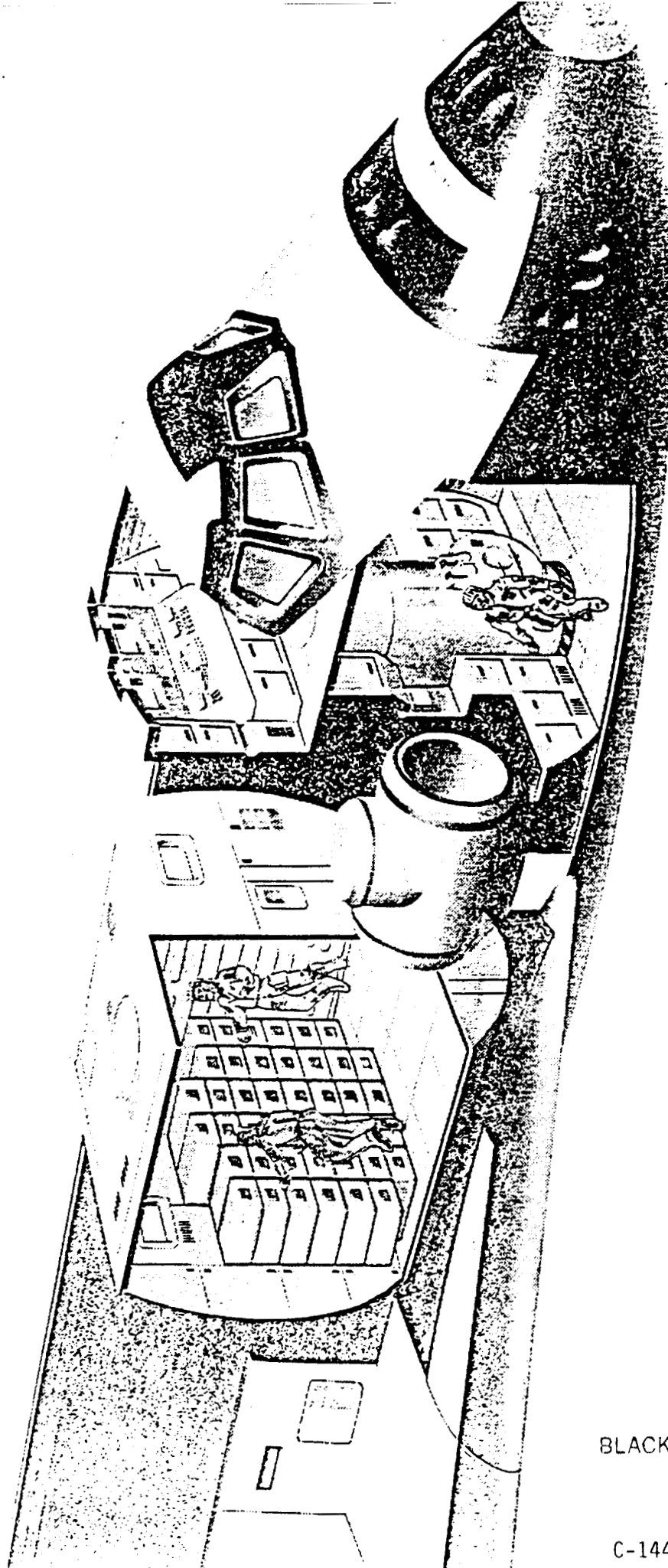
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# **SPACEHAB**

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## **Middeck Augmentation Market**

- Middeck Type Locker Experiments
- Spacelab Experiments
- Specific Experiments Requiring Man Tended Capability
- Specific High Priority Military Experiments
- Additional Crew Stowage Requirements
- Commercial Researchers
- Life Science and Others Requiring Isolated Manned  
Volume in Orbit



SPACEHAB MIDDECK AUGMENTATION MODULE  
IN ORBITER PAYLOAD BAY

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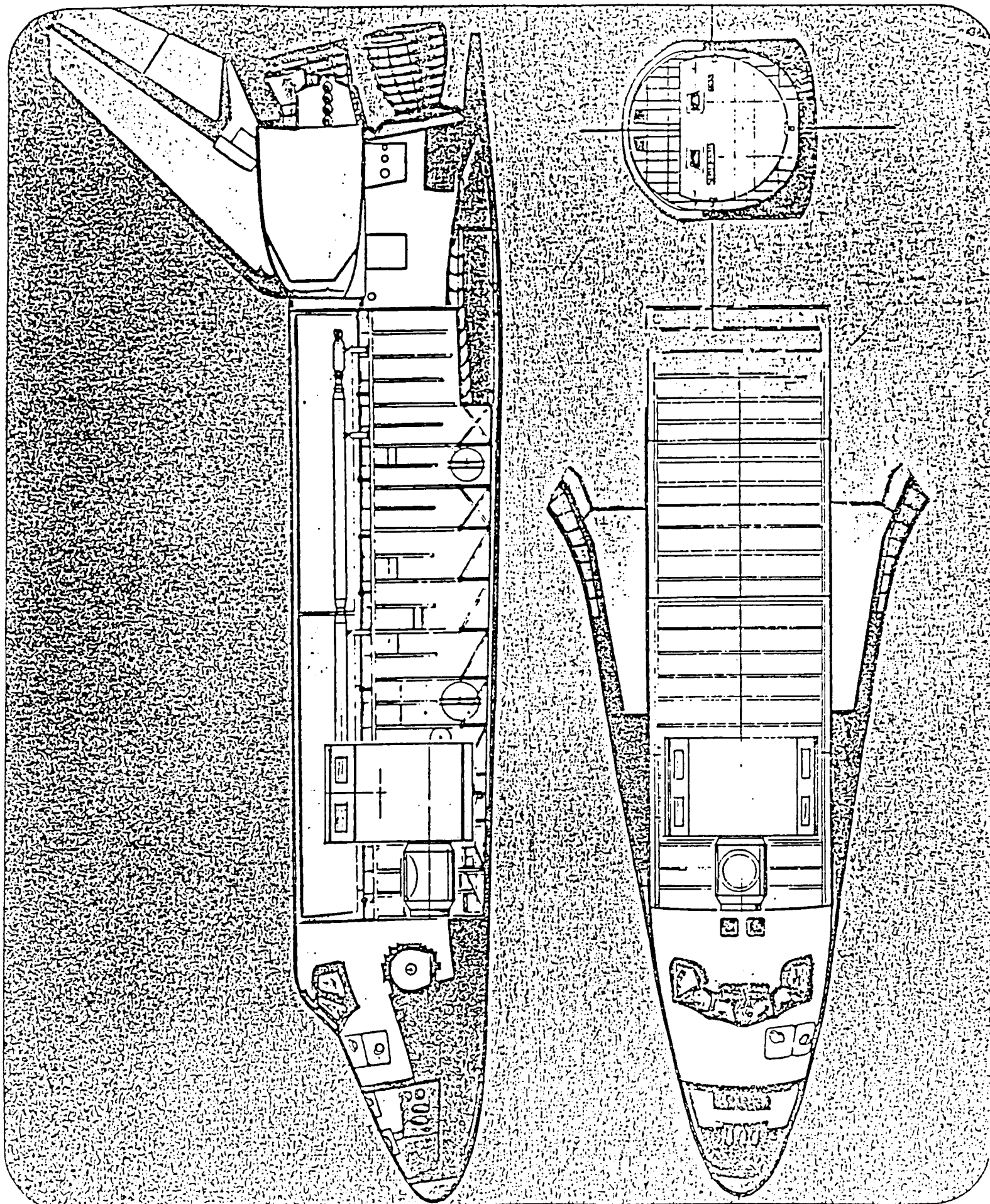
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# SPACEHAB

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## Roles

- SPACEHAB, Inc. is a privately financed venture in America's emerging Space Commercialization industry.
- McDonnell Douglas Astronautics Company is SPACEHAB's Prime Contractor for Developing the Spacehab Module.
- Aeritalia is the Sub-Contractor to MDAC for Designing and Building the Primary Structure.

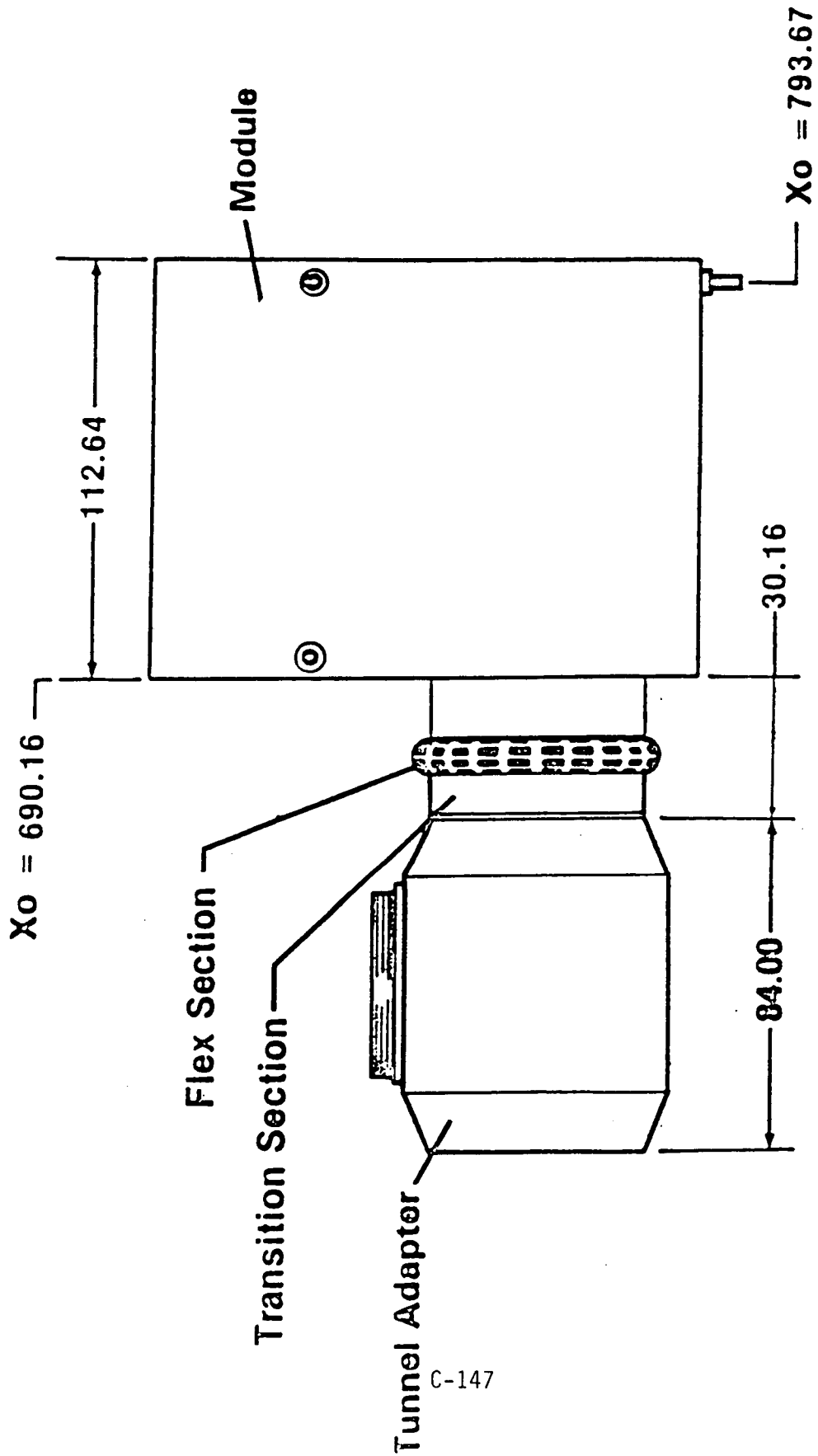


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0 146

# SPACEHAB



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Installed Configuration

# SPACEHAB

## Internal Volume

USEABLE VOLUME = 988 Cu Ft

Total Useable  
Volume = 988 Cu Ft

10" I Beams  
typical

$X_0$

86"

6" I Beams  
typical

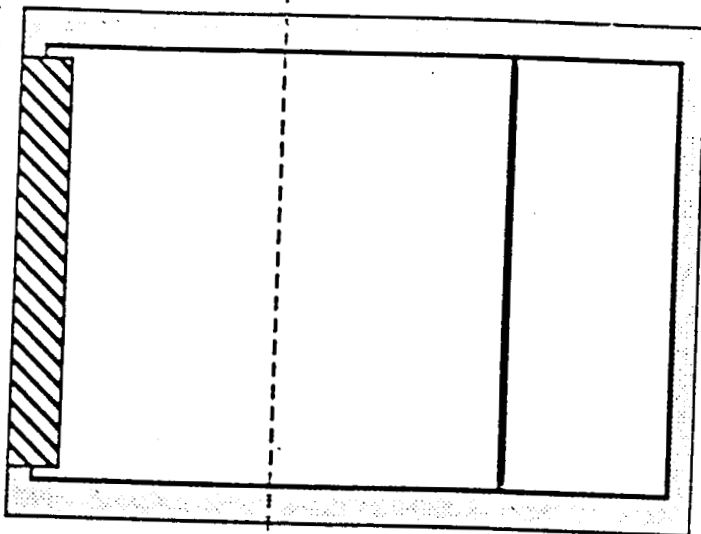
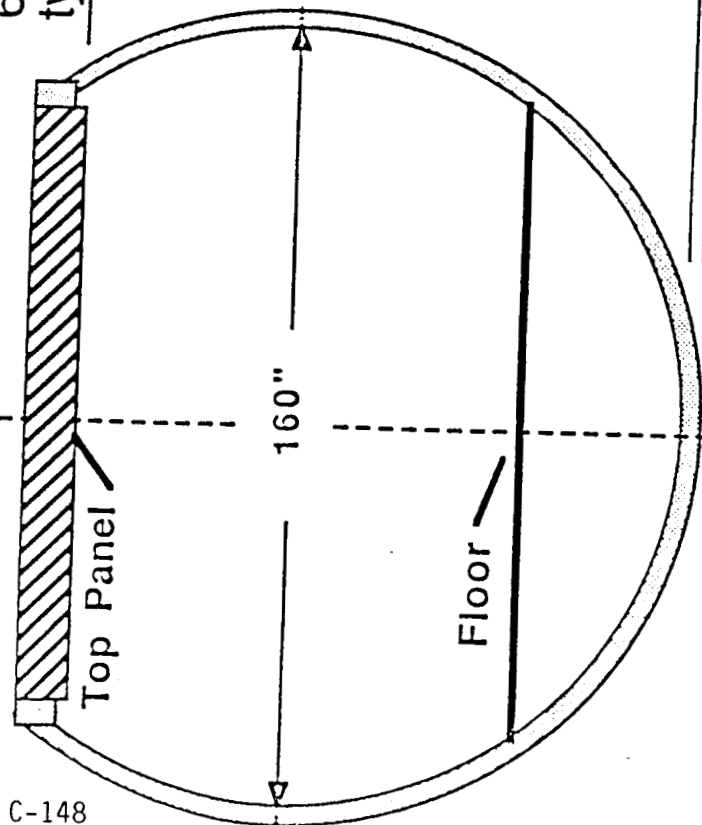
53"

92"

80"

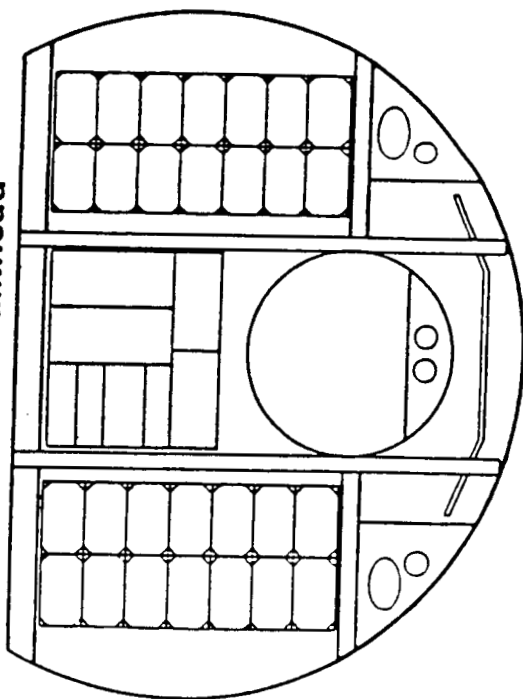
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C-148

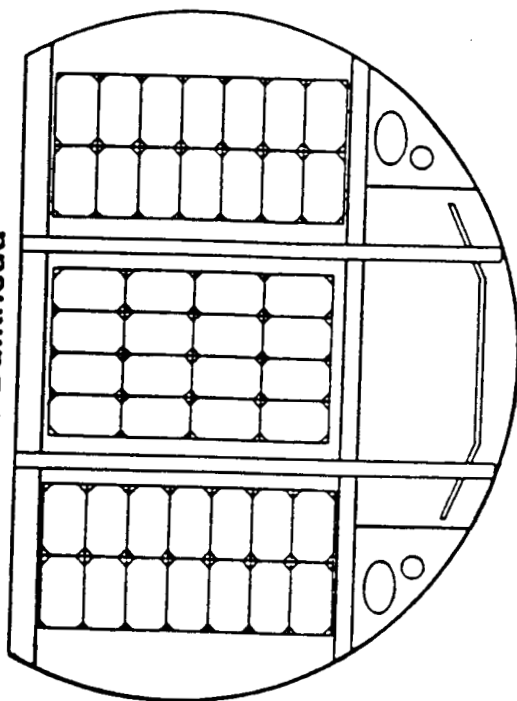


# SPACEHAB

Forward Bulkhead



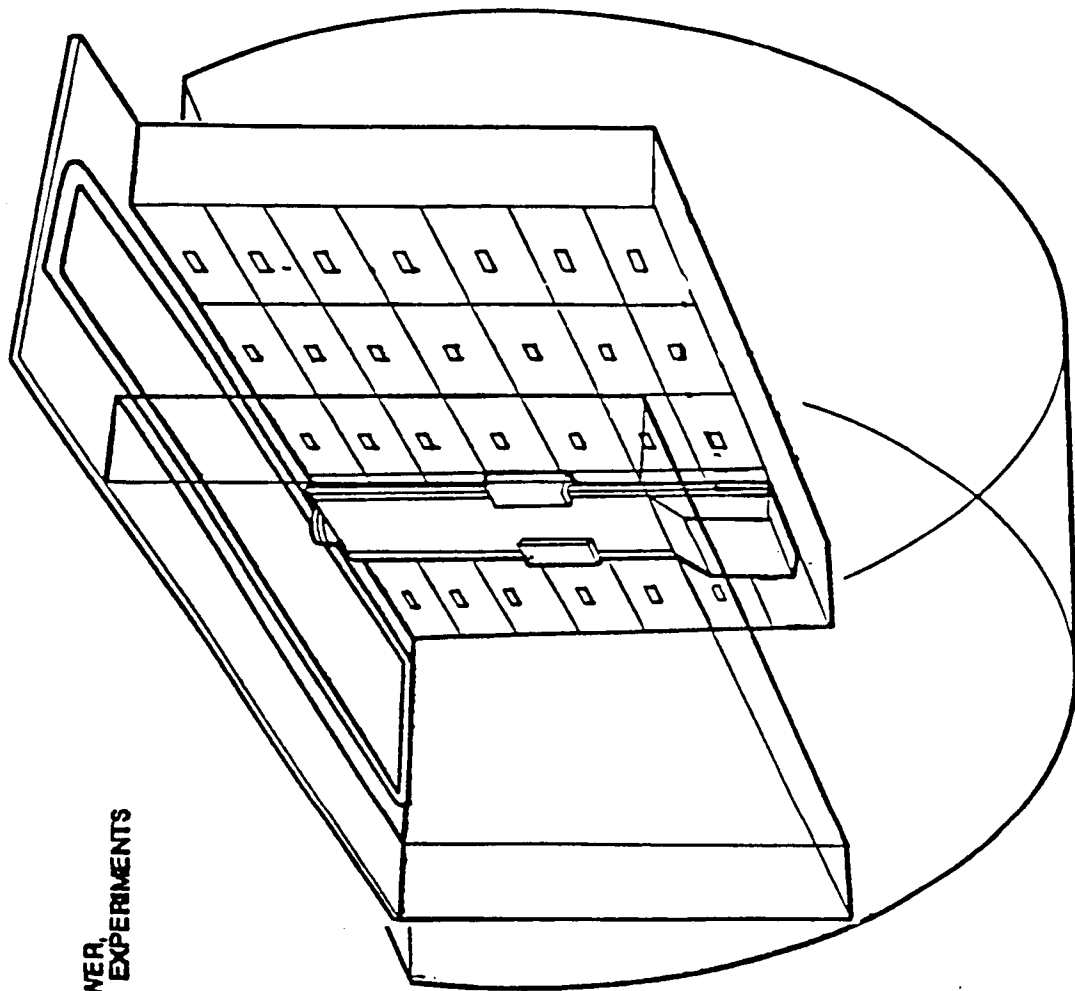
Aft Bulkhead



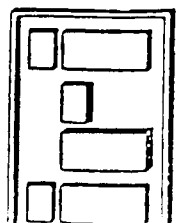
Payload Accommodations  
72 LOCKERS

# ROBOTIC SERVICING OF MIDDECK LOCKERS

ROBOTIC ARM SUPPLIES POWER,  
CONTROL AND COOLING TO EXPERIMENTS  
IN SEQUENCE



C-150

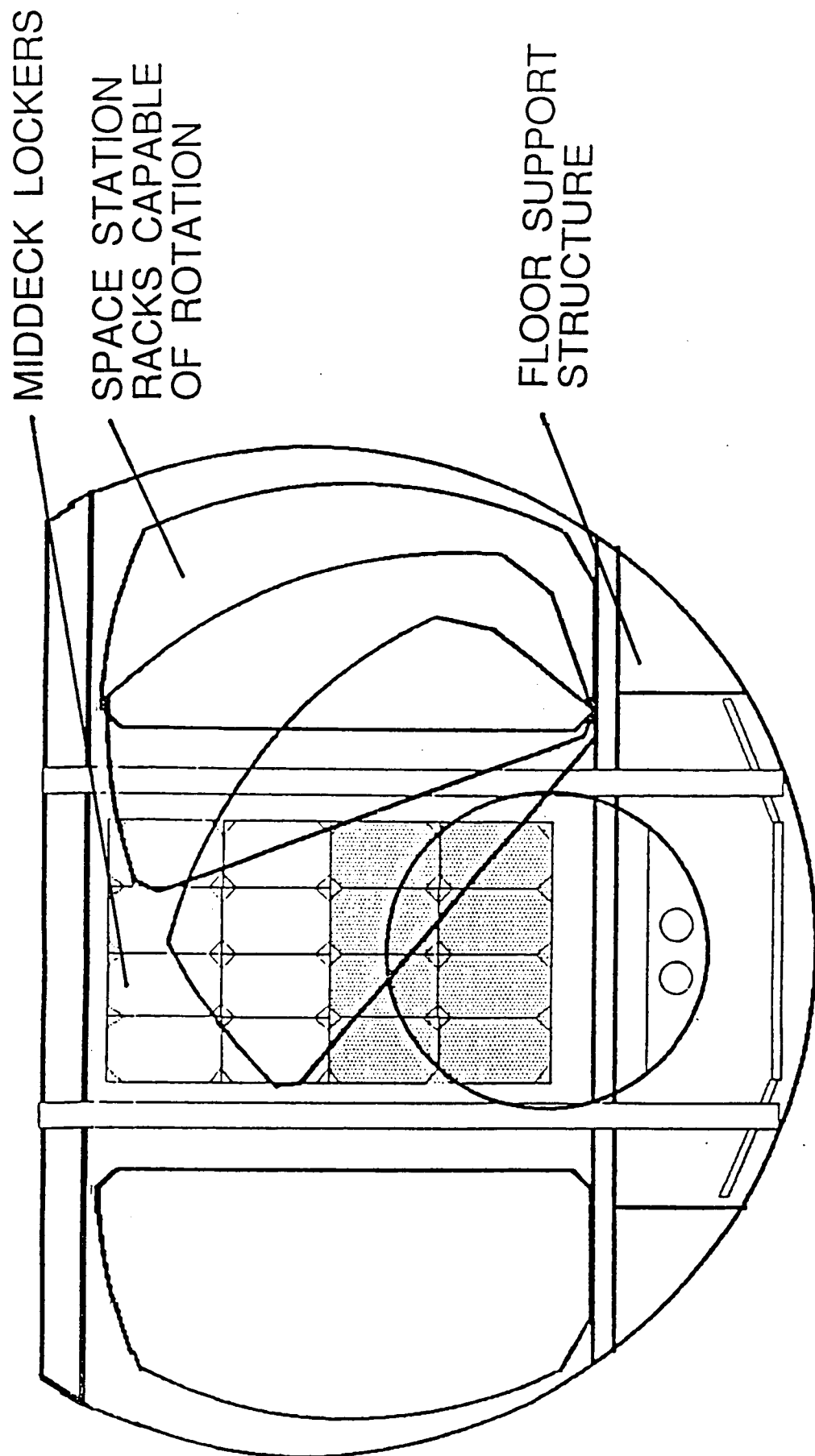


INTERLAB ROBOTICS, INC.

**SPACEHAB**  
DEVELOPERS OF SPACE SHUTTLE HABITAT MODULES



# SPACEHAB

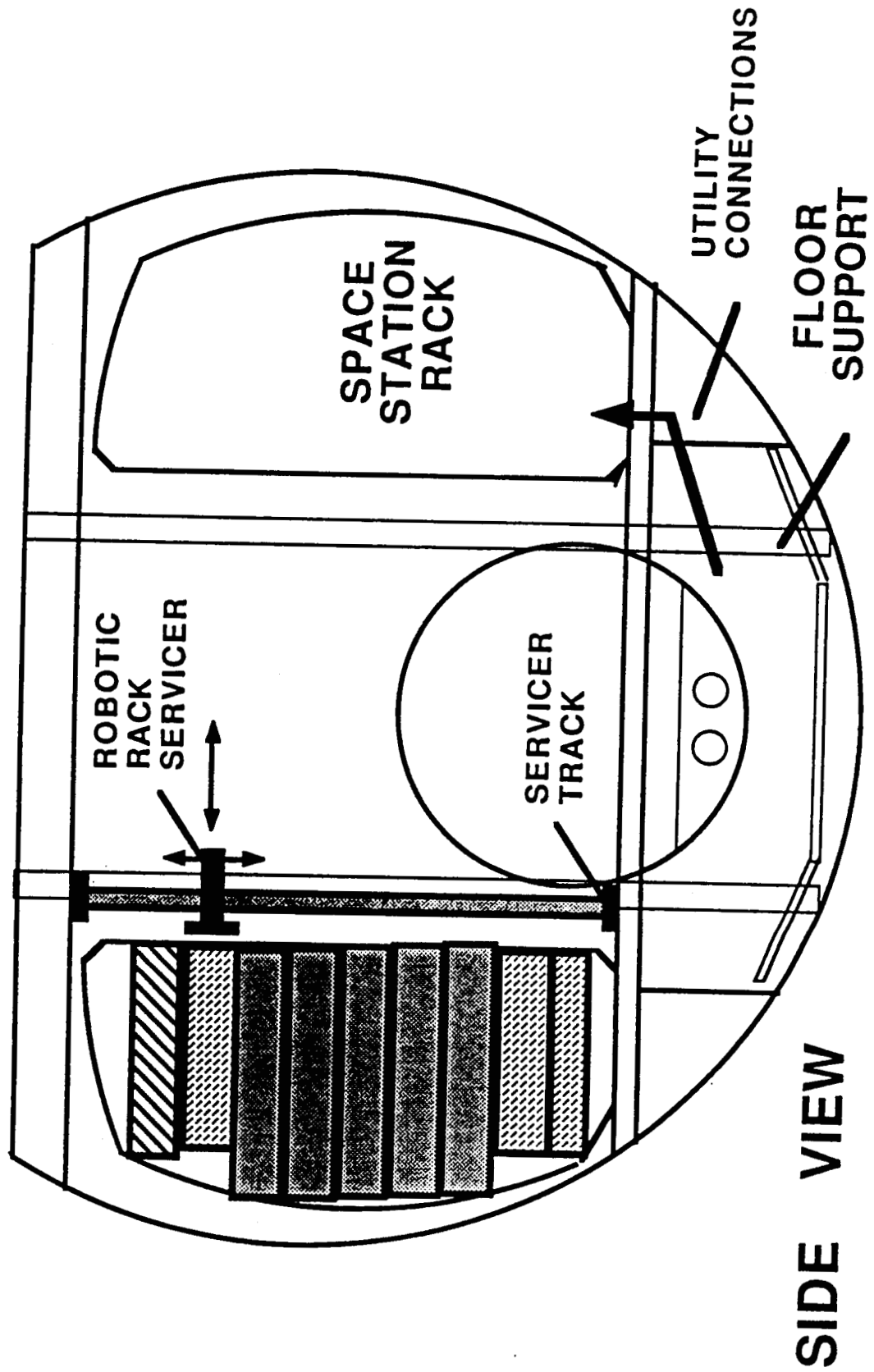


C-151

MCDONNELL DOUGLAS

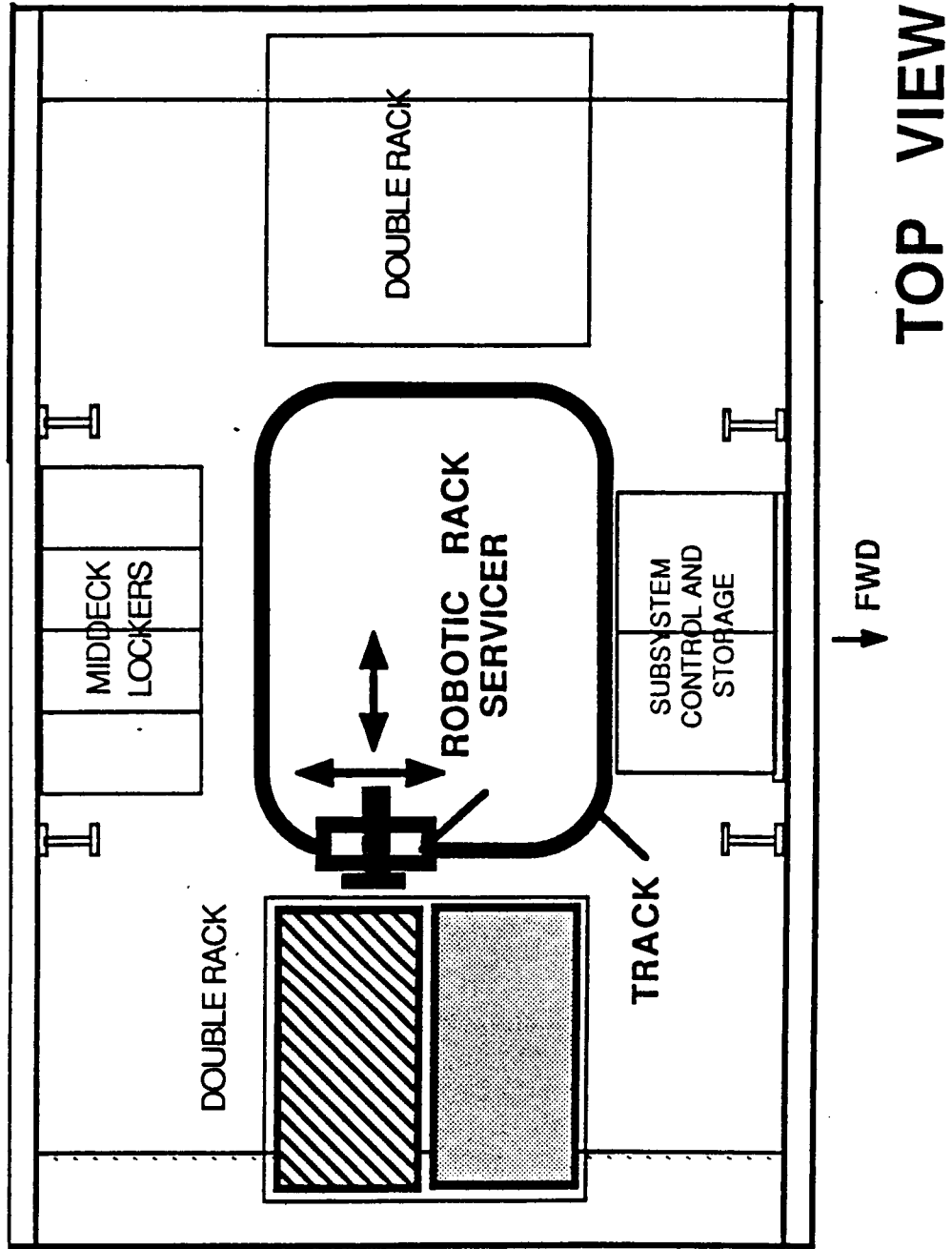
# SPACEHAB

## ROBOTIC RACK SERVICER



# SPACEHAB

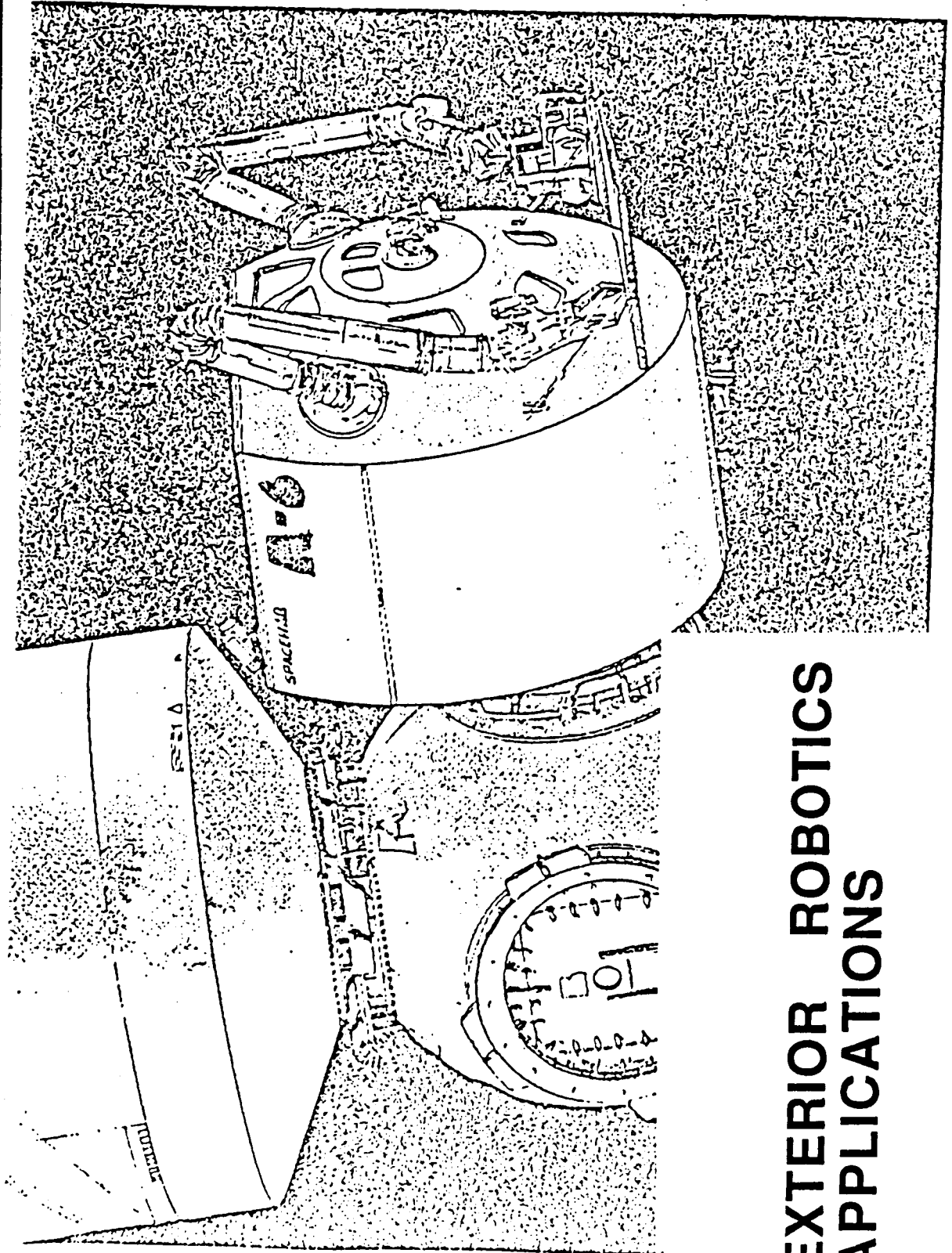
## ROBOTIC RACK SERVICER



C-3

# SPACEHAB

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EXTERIOR ROBOTICS  
APPLICATIONS

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# SPACEHAB

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## EXPERIMENTER UTILITIES

- POWER
- HEAT REJECTION
- DATA MANAGEMENT
- MAN TENDING
- INTEGRATION
- ACCESS TO VACCUM
- LATE ACCESS/EARLY RECOVERY

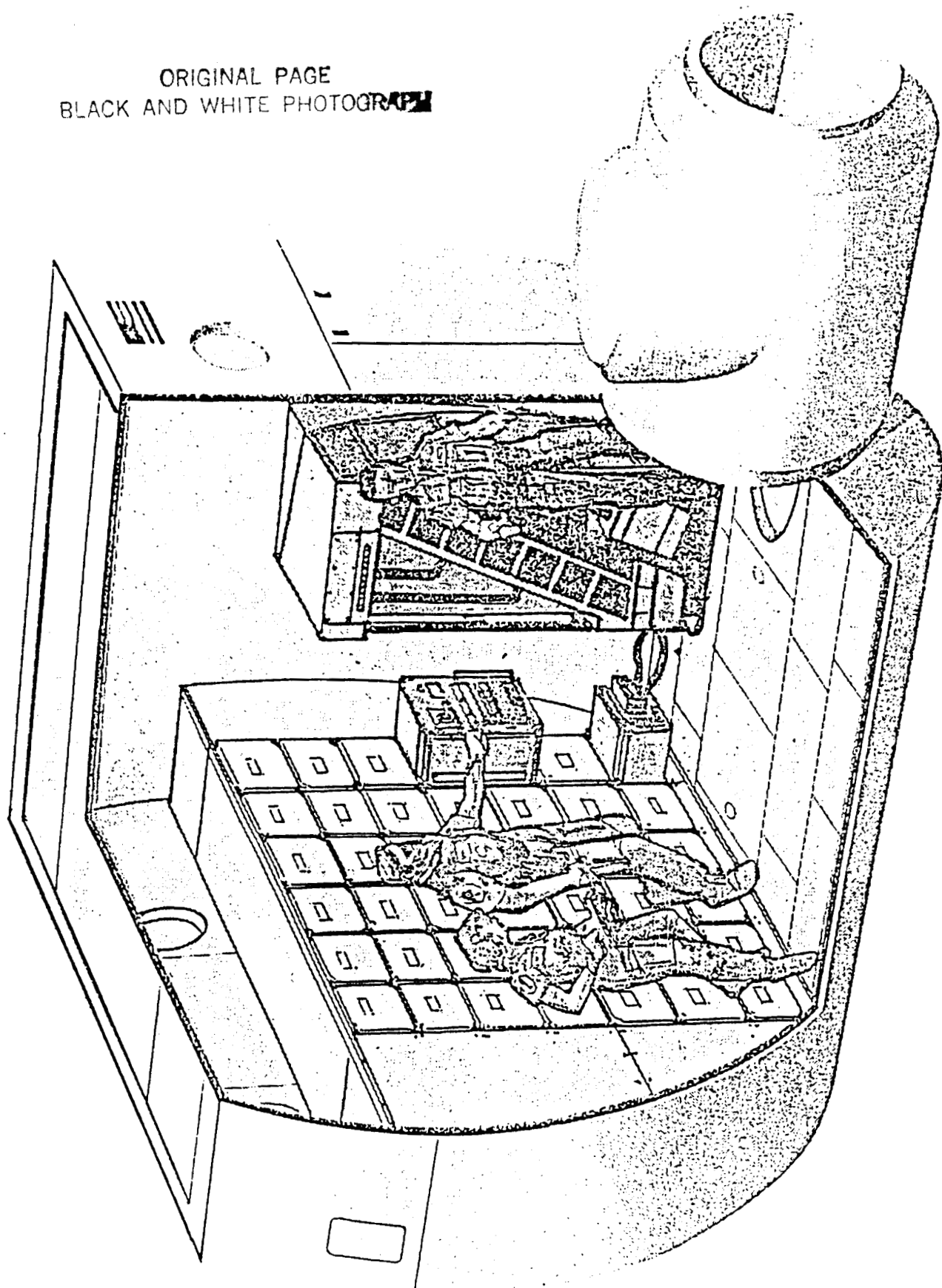
# SPACELAB

Mission Phase	Power (KW)			Time Limit on Peak Power
	1 SMCH		2 SMCH	
	Max.Cont.	Peak	Max.Cont.	Peak
On-Orbit	1.45	2.7	3.2	5.7
Ascent/ Descent	.22	.72	.22	.72
				15 Min./3 Hr.
				2 Min/ Mission Phase

## PAYLOAD DC POWER ACCOMMODATION

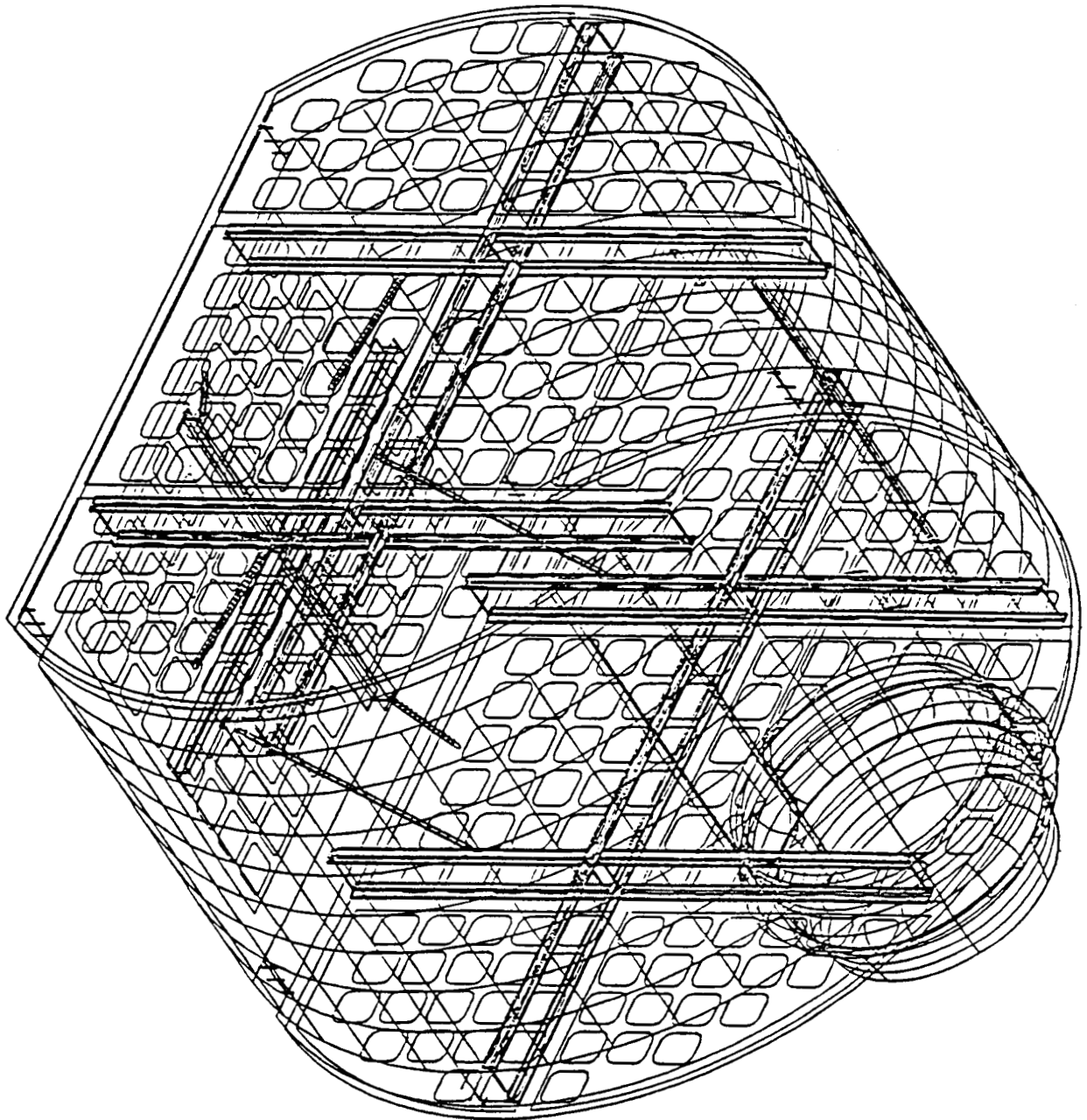
MCDONNELL DOUGLAS

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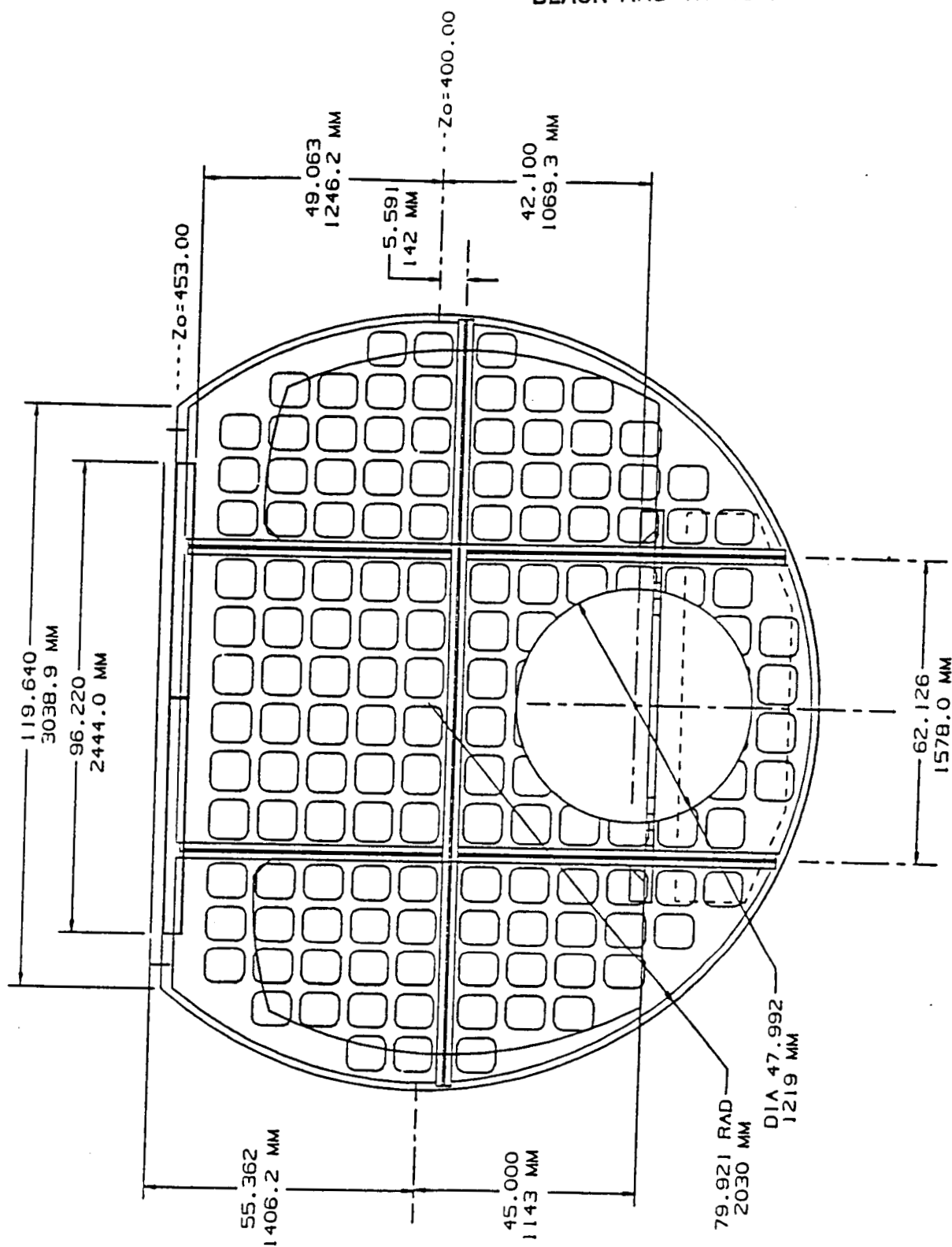
SPACEHAB

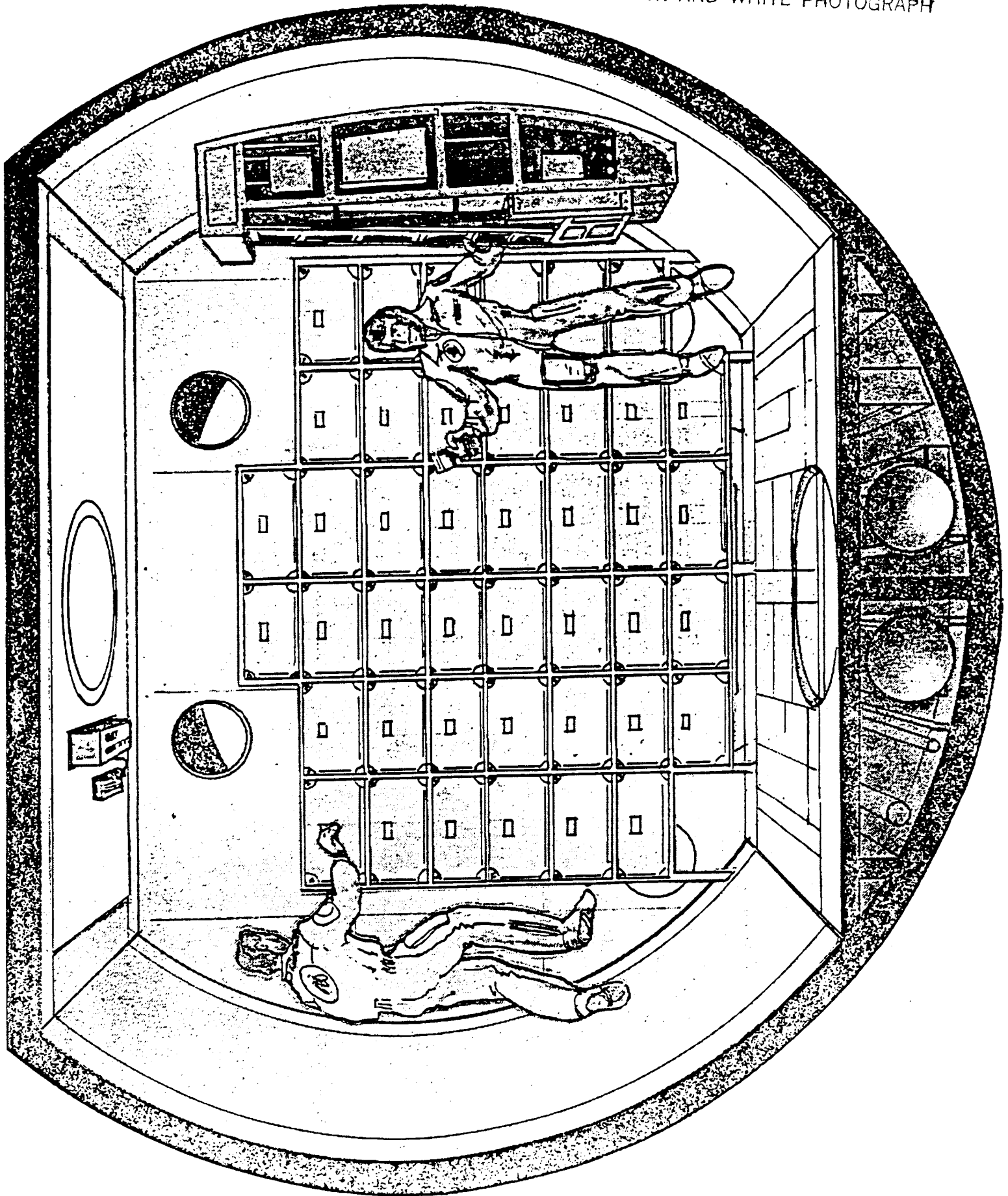




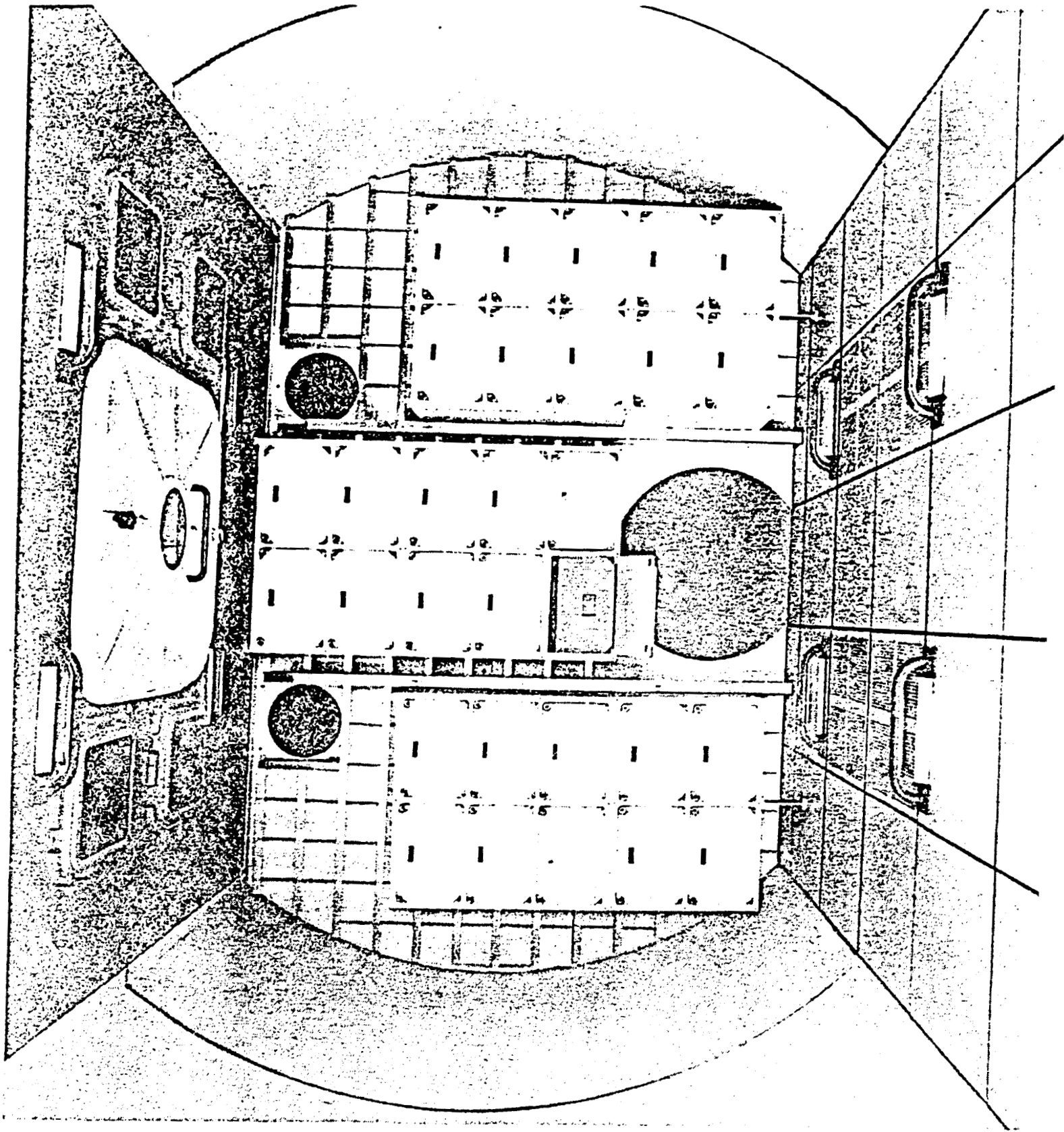
# SPACETAB

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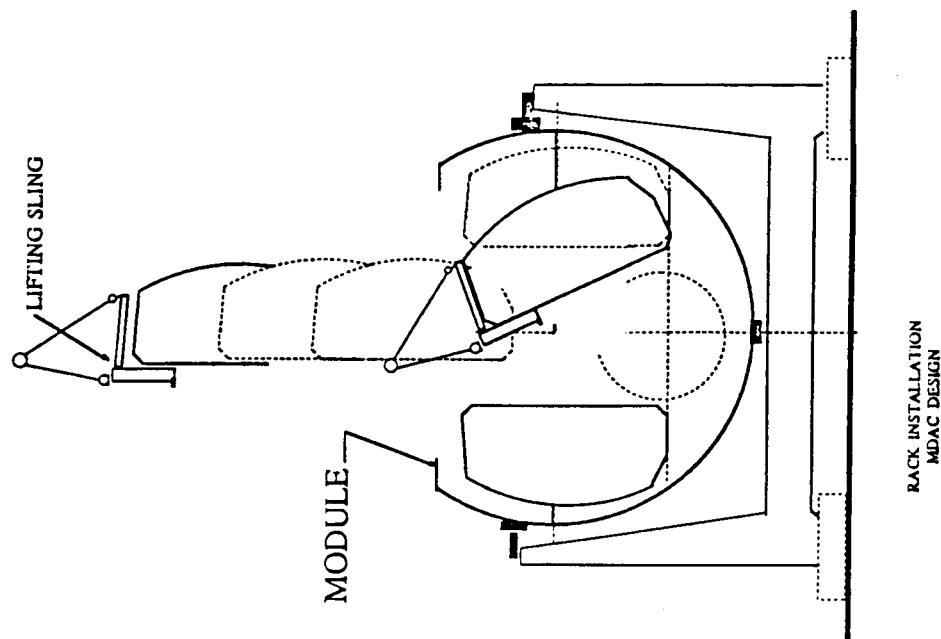




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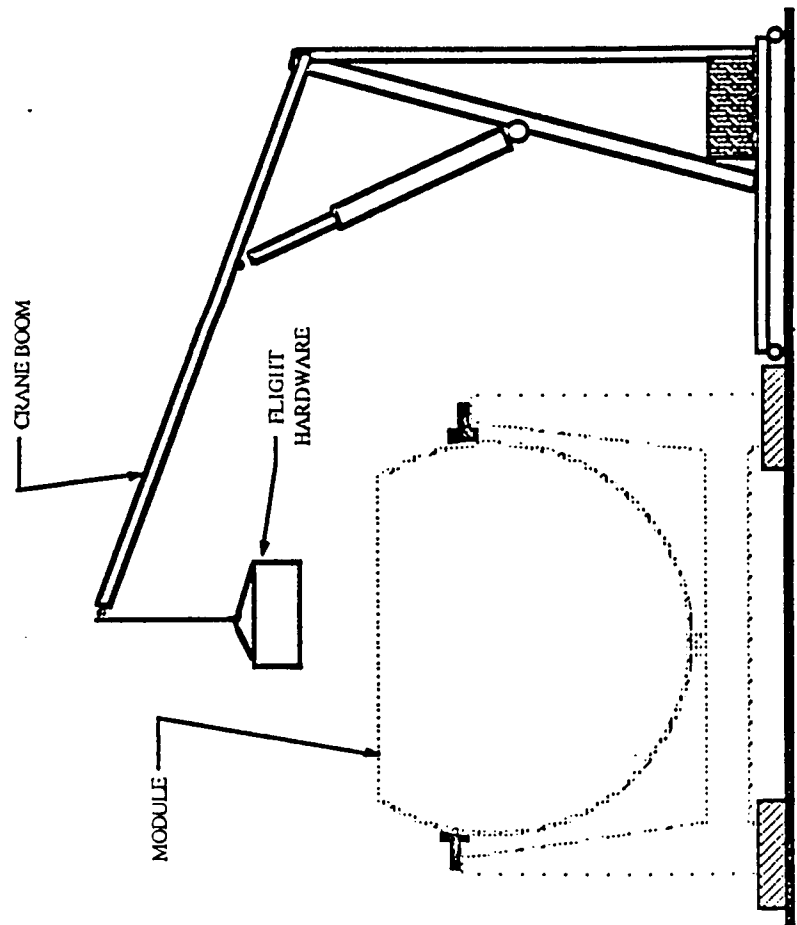


# SPACEHAB



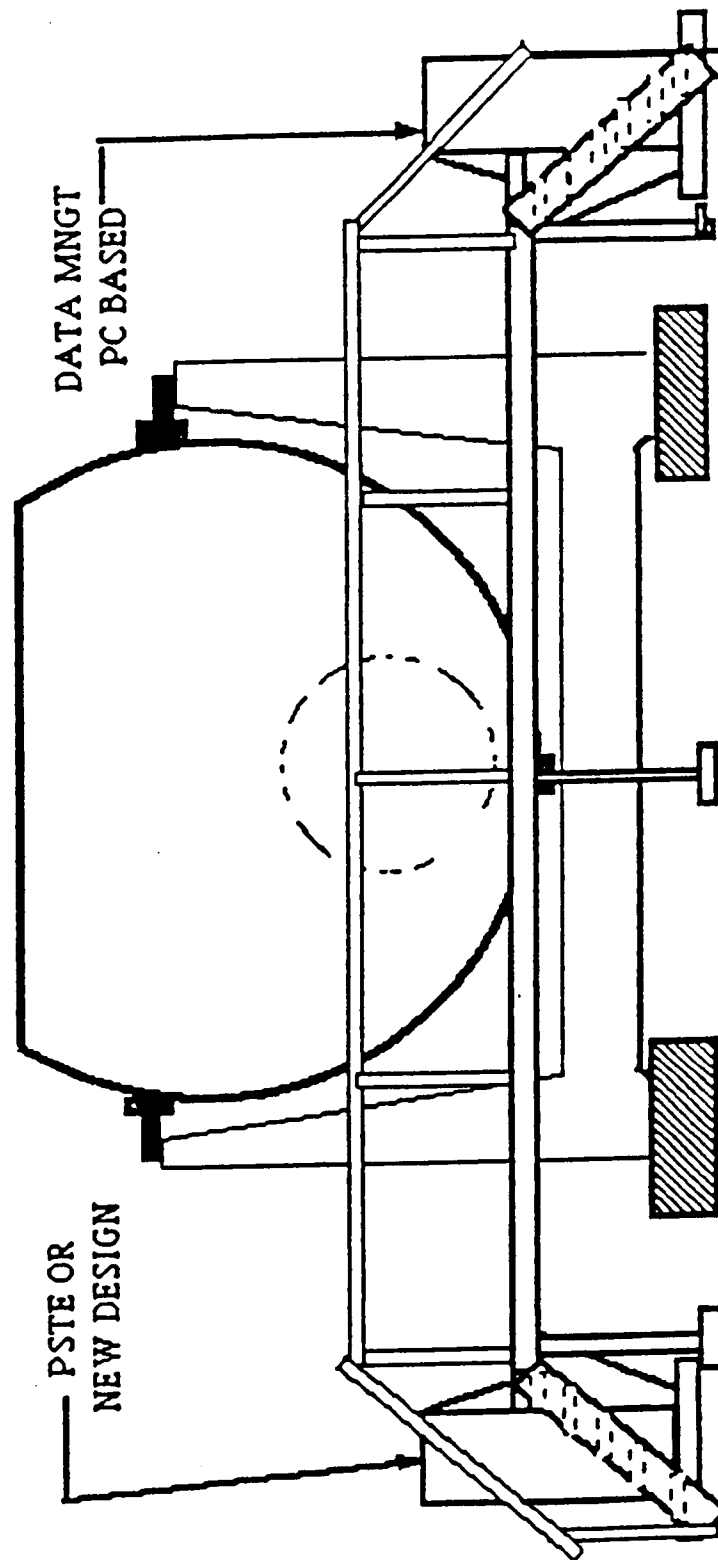
INTEGRATION OF SPACE STATION TYPE RACKS INTO THE SPACEHAB  
MODULE CAN BE ACCOMPLISHED SIMPLY THROUGH THE OPENING IN  
THE TOP. SPECIAL GSE WILL BE REQUIRED FOR THIS OPERATION  
WHICH WILL REQUIRE OVERHEAD LIFTING CAPABILITY.

# SPACEHAB

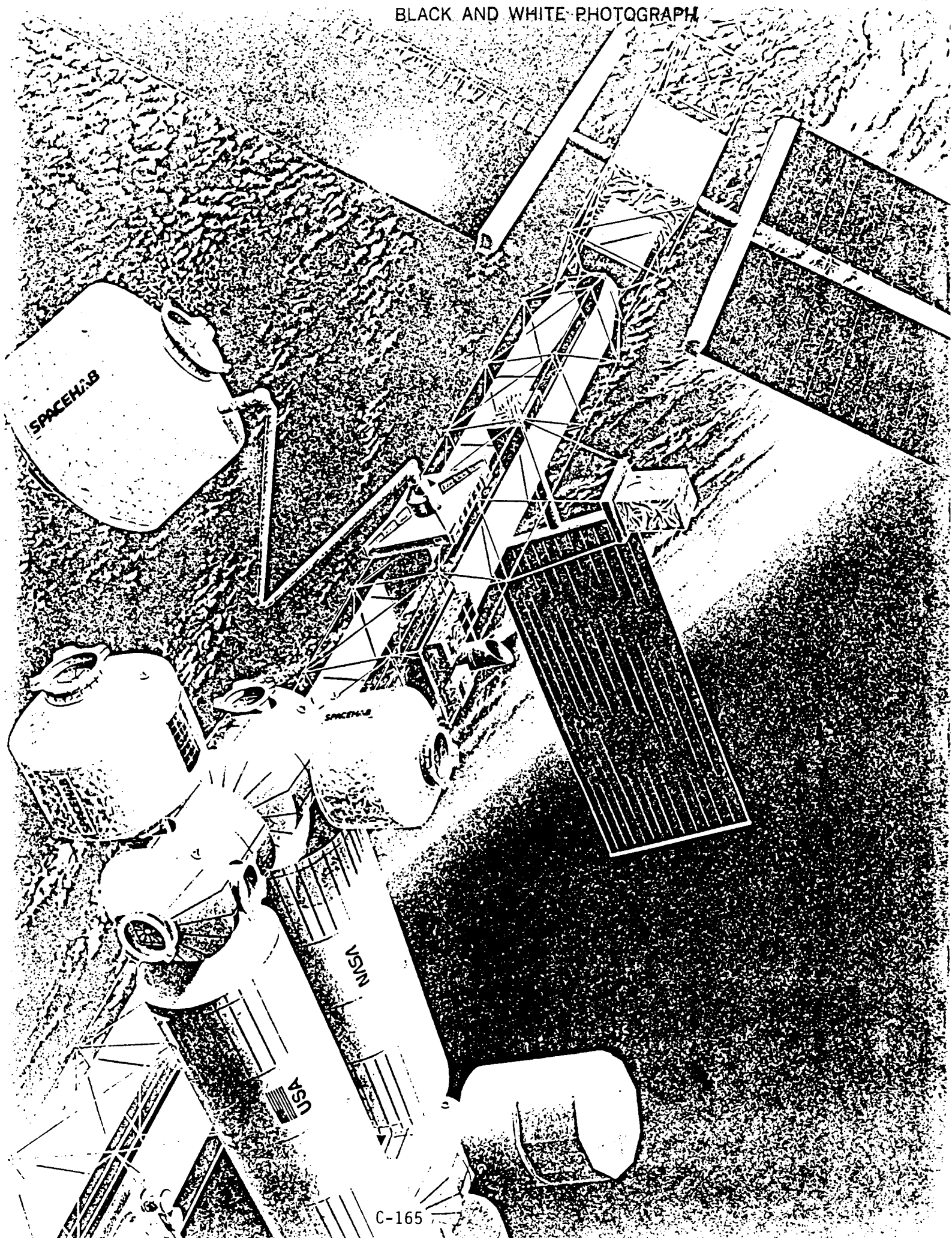


SIMPLE CRANE  
OPERATIONS

CRANES AND GANTRYS ARE COMMERCIALY AVAILABLE TO COVER MOST OPERATIONS IN THE INTEGRATION BUILDING. THESE PORTABLE UNITS WILL BE COMPATIBLE WITH THE SCOPE OF PORTABILITY OF OTHER GSE AND ELIMINATE THE NEED FOR OVERHEAD CRANES.

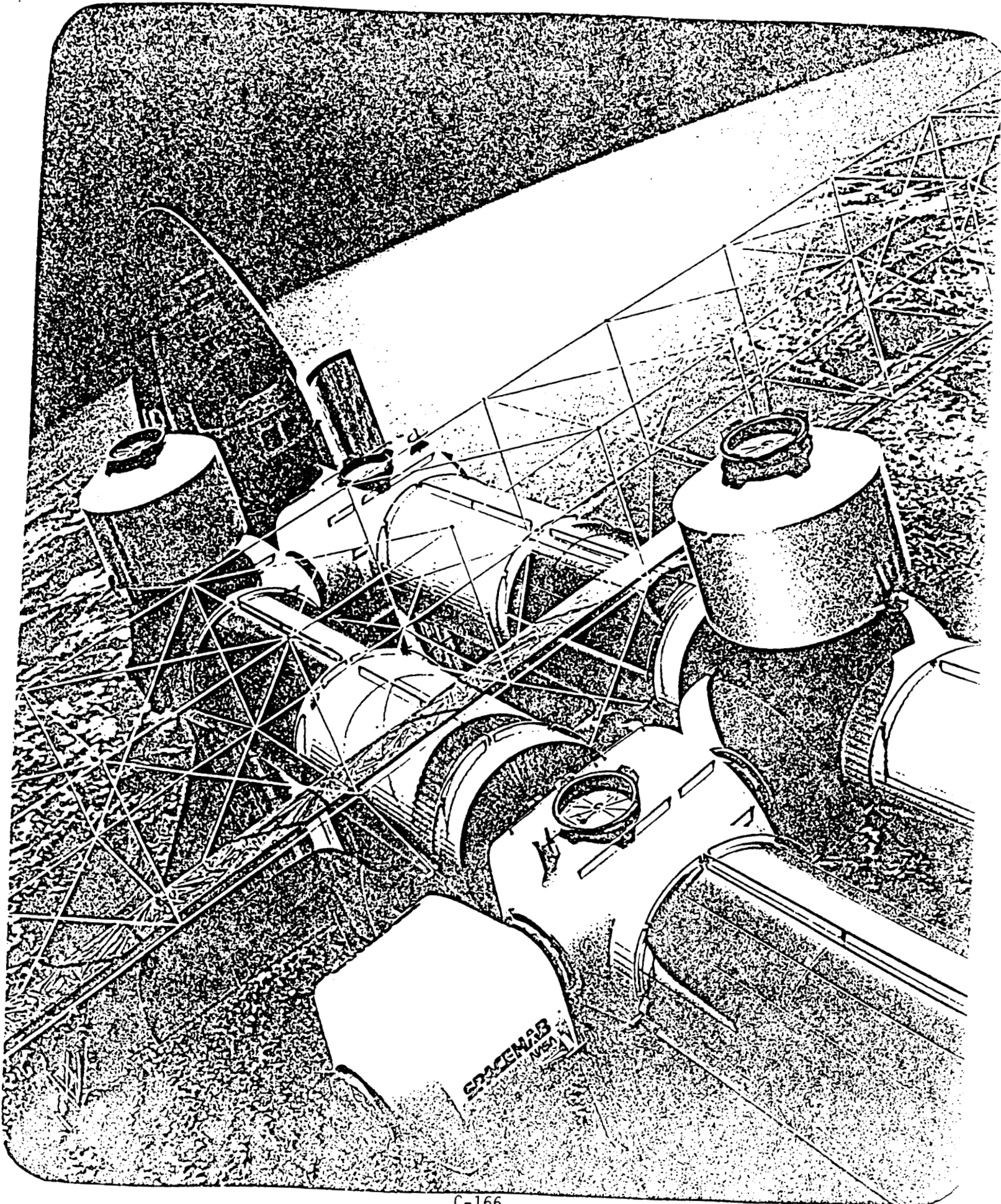


# SPACEHAB WORKSTAND AND PLATFORM





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## **Critical Issues - Workshop**

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- **Early Flight Test Designed for Development of Commercial Micro-electronic Processes Systems**
- **Space Application of current State of the Art and not a new program of re-invent**
- **Acknowledge man will be involved throughout the entire development and production process**
- **Work for Innovation in Robotics using standard equipment**

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## **Conclusions**

- **Module Designed Development of Robotic Systems**
  - **Uses Existing Lockers, Racks and Components when Possible**
  - **Capable of Robotics User Defined Flight Test**
  - **Allows for Innovation in Robotics Control**
    - **Interior Volume**
    - **Exterior, Aft Exterior Bulkhead Surface**
    - **Exterior, Deployed Module**
  - **The Proposed Robotics Development Process**
  - **The Robotics Follow-on Possible**
-